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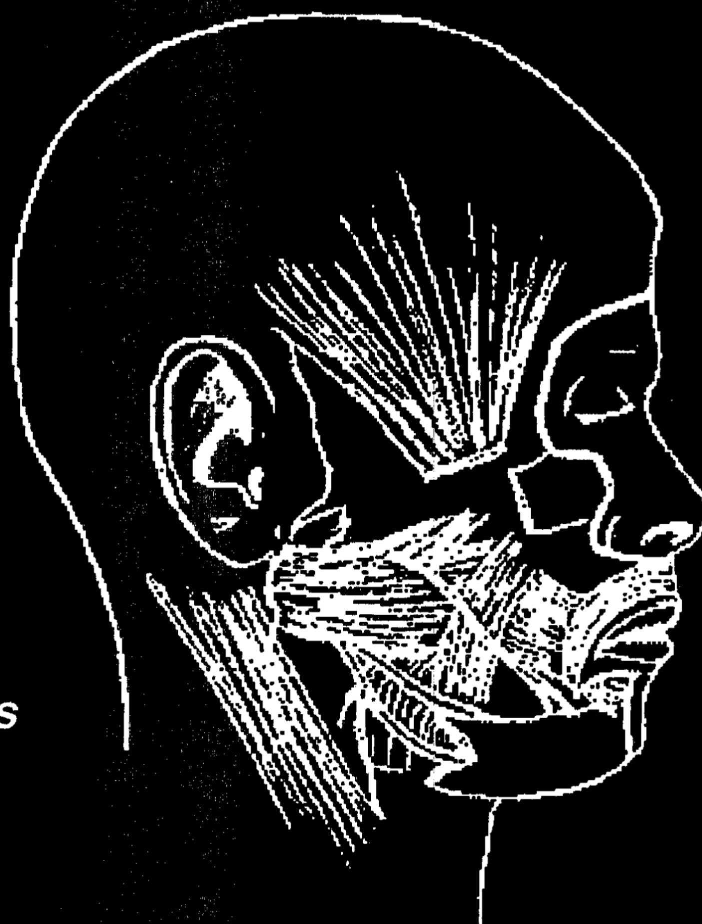
Dissection of the Speech Production Mechanism

The UCLA Phonetics Laboratory



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Dissection of the Speech Production Mechanism

by

The UCLA Phonetics Laboratory

This manual has its foundation in more than 25 years of research on the anatomy of the speech production mechanism. The current version is the work of many members of the UCLA Phonetics Lab, including: Sean Boisen, Sarah Dart, Karen Emmorey, David Feldman, Juan Carlos Gallego, Robert Hagiwara, Kenneth Hill, Caroline Henton, Ren Hongmo, Marie Huffman, Sue Inouye, Michel Jackson, Jenny Ladefoged, Peter Ladefoged, Mona Lindau, Ian Maddieson, and Rich Robison. Special thanks are due to Peter Duong and Kevin Hori of the UCLA Anatomy Department who guided the members of the Phonetics Lab with great expertise and kindness, and who were a major resource in the preparation of the manual.

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0. Introduction

This manual has been written in the hope of urging as many students of speech as possible to find a co-operative anatomy department and to try dissecting a human cadaver for themselves. One can have access to all the knowledge available from anatomical atlases and textbooks on speech production; but none of it substitutes exactly for the hands-on experience acquired in the laboratory. There is nothing comparable with actually seeing where muscles of the tongue attach, feeling the thickness of the trachealis muscle, moving the arytenoid cartilages and holding a brain in one's hand.

The aim of this practical manual is to guide students in their dissections. There are several books that describe the anatomy and the physiology of the vocal apparatus, notably Hardcastle (1976), Zemlin (1981), and Dickson and Maue-Dickson (1982). Students are encouraged to study these books in order to gain a theoretical understanding of the speech production mechanism. Further suggestions for reading appear in the annotated bibloigraphy in Appendix C. There is also an excellent atlas specifically for speech and hearing scientists by Kahane and Folkins (1984). We hope that this manual will help students take a small step towards preparing dissections like those shown in the wonderfully detailed photographs in that book. Throughout this dissection manual we will refer to particular figures in Kahane and Folkins, which illustrate model dissections that students should try to emulate.

As far as we know, there is no dissection guide primarily directed towards students of speech. Much of the contents in standard dissecting manuals such as Grant's dissector (Sauerland, 1984) cover anatomical areas irrelevant to the mechanism of speech production, i.e. the arms, the legs, and most of the lower abdomen. Accordingly, we have tried to produce a method of dissection concentrating mainly on the thorax, the neck and the head. Even with this limited region we have severely limited our goals. Speech scientists do not need to know how the heart should be examined, nor the appropriate way of dissecting the eye. Throughout we have emphasized only anatomical structures relevant to speech.

We assume that the specimen available for study is a human torso, transversely sectioned well below the level of the diaphragm and properly embalmed. When dissecting a body one must always take care to prevent the body from becoming too dry by wrapping it in cheesecloth dampened with a suitable preserving fluid, after every dissection. The skin of the specimen is also a good protection against drying. The skin should be removed only when the area underneath needs to be studied.

Students should be aware that the actual cadaver they dissect may have individual characteristics such that the dissection procedure specified here has to be modified. Often muscles that are described in text books cannot be found in a given individual. Sometimes they are much more prominent on one side than another. The cadaver may not have teeth. People end up in an anatomy lab because they died of some cause - which may have involved a collapsed lung, or a carcinoma of some sort. They are nearly always old, and their muscles may not be as prominent as they once were.

The tools needed for dissection are a scalpel, a blunt-ended probe, a pair of scissors, and a pair of blunt-pointed forceps. In addition, larger tools such as a bone saw, a pair of shears, a mallet and a chisel are occasionally necessary. The availability of an electric autopsy saw is invaluable in speeding up certain procedures such as the opening up of the skull.

A glossary of anatomical terms will be found in Appendix A. As in standard anatomical texts, we will adopt the convention of describing planes, positions or relationships by referring to the cadaver as if it were standing erect with the arms straight down by the sides. This is not necessarily the position of the cadaver during dissection, but it allows for a common basis for all descriptions. Thus even if the cadaver is lying on its back, the sternum is described as being below the head. The most important terms and their use are illustrated in Figures 0.1 - 0.3.

Appendix B contains a list of all the most important muscles of the speech production mechanism, arranged in accordance with their function. Students should review appropriate sections of this list periodically, so as to ensure that they have seen all the muscles named. The annotated bibliography in Appendix C contains references to some useful supplementary materials.

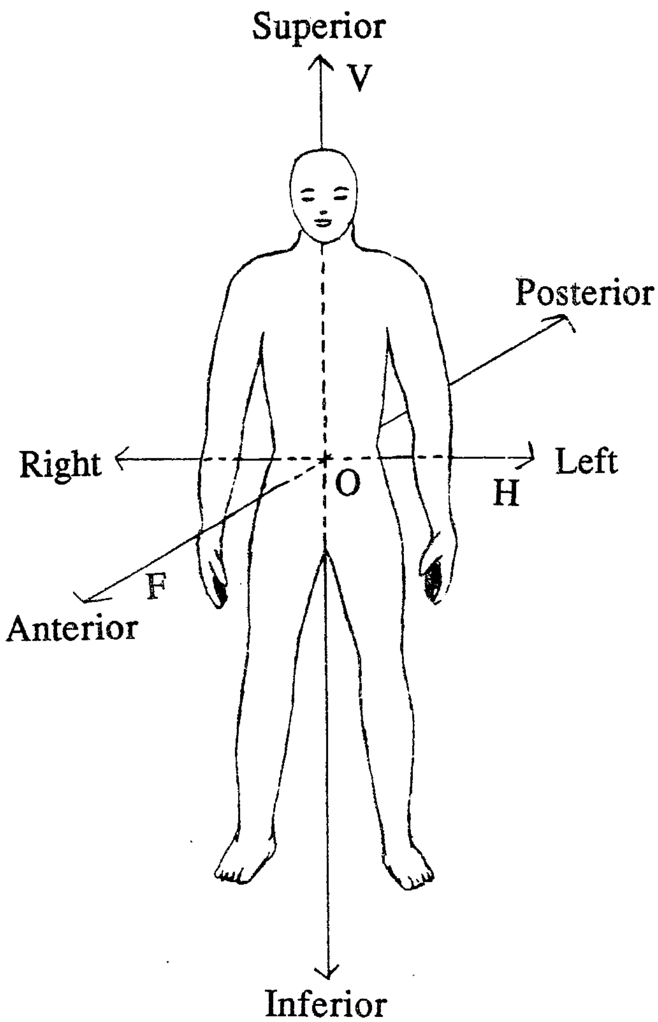

Figure 0.1. The three principal axes. A vertical axis (V), on which is defined *superior* and *inferior* ; a horizontal axis (H), on which is defined *left* and *right*; a forward axis (F), on which is defined *anterior* and *posterior* . *Deep* is defined as 'closer to the point of origin (O) relative to something else'; *surface* (or *superficial*) is defined as 'further from the point of origin'. The three axes may be relativized to whatever structure is considered (e.g. when considering the brain, it is useful to consider the point of origin as being within the head, as opposed to these examples, where it is inside the body.

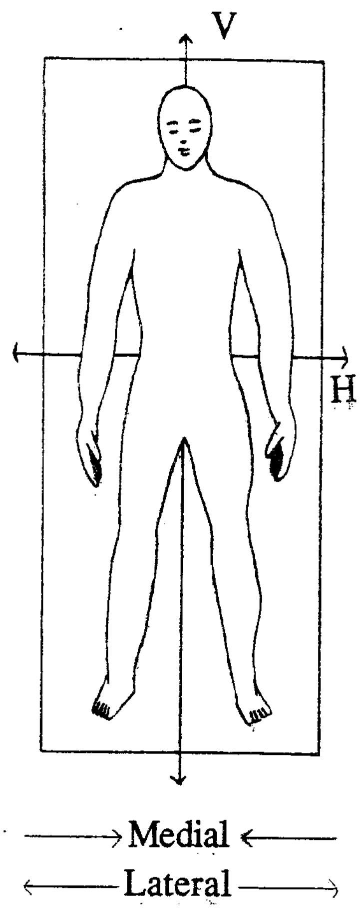

Figure 0.2. A *coronal* plane, defined by vertical and horizontal axes. *Medial* is defined as 'toward the *midline* (in this figure, the vertical axis) in a coronal plane'. *Lateral* is defined as 'away from the midline in a coronal plane.

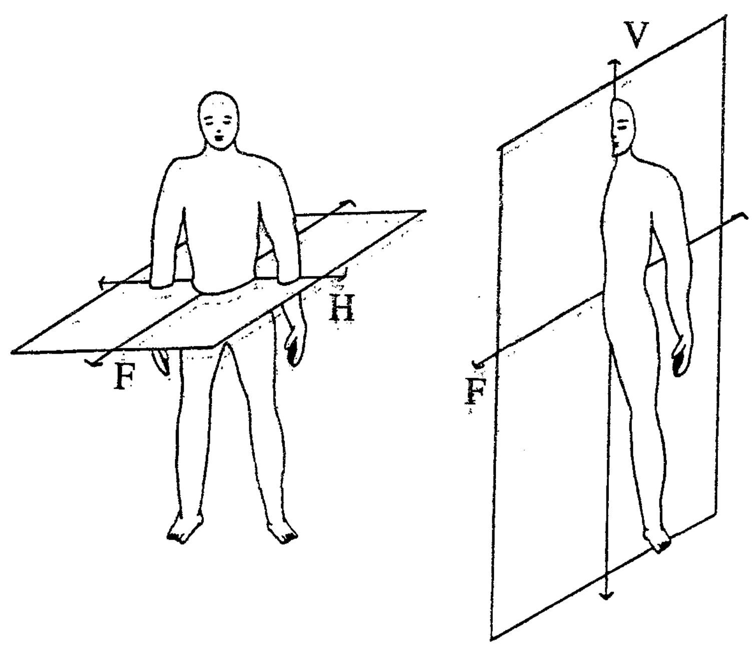

Figure 0.3. T*ransverse* and *sagittal* planes. A transverse plane, left, is defined by horizontal and forward axes. A *sagittal* plane, right, defined by vertical and forward axes. Some sources distinguish sagittal planes generally from the *median* (or *mid-sagittal*) plane, a sagittal plane which runs through the midline (as shown here.)

1. The Respiratory Mechanism

The object of the first dissection is to examine the respiratory mechanism as it is used in speech production. Speech involves first filling the lungs with air and then pushing this air out so as to supply sufficient power for the production of the various sounds.

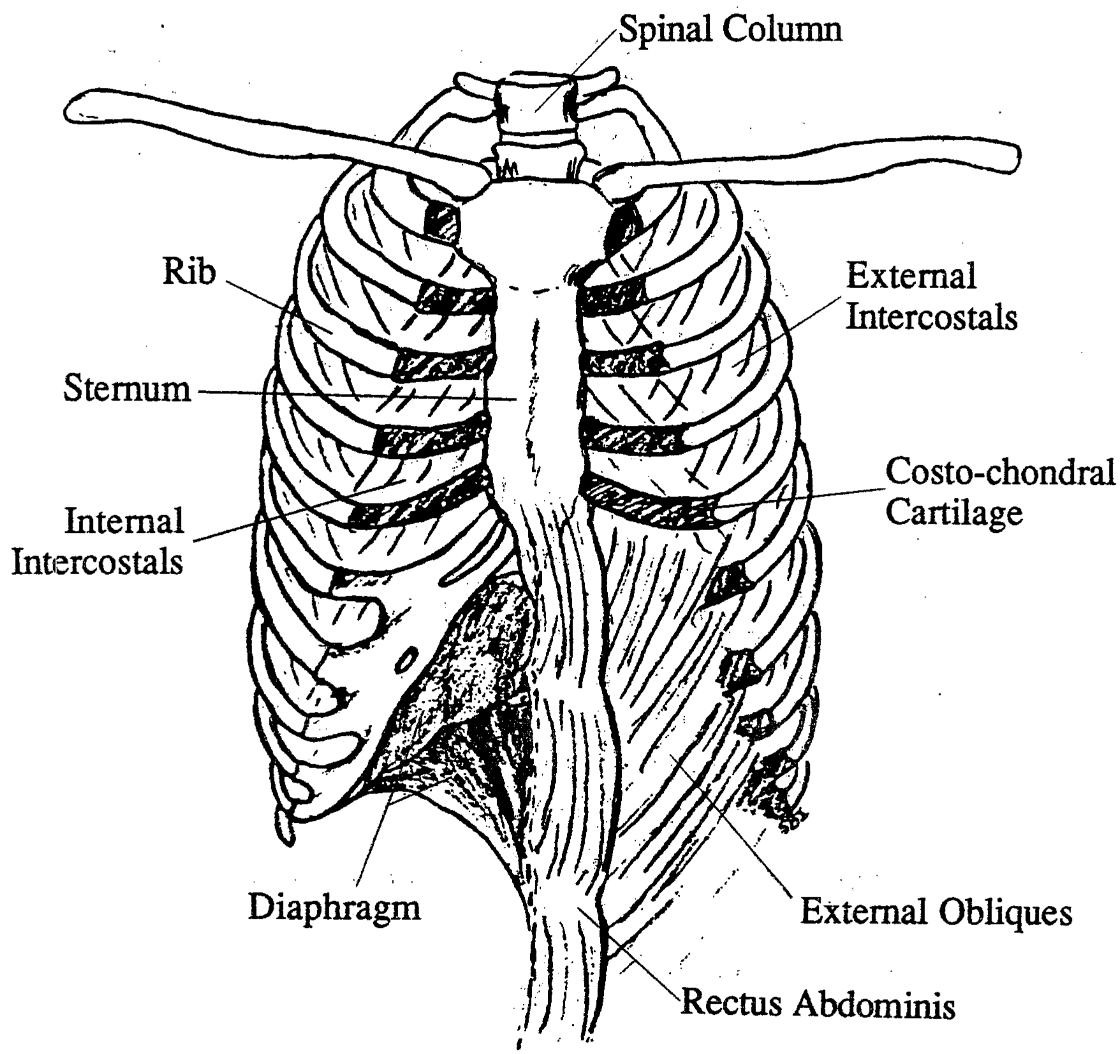

Figure 1.1. The respiratory mechanism.

Inspiration is the result of raising and widening the rib-cage, by the contraction of the external intercostal muscles, and contracting, and thus lowering, the domes of the diaphragm. The external intercostals are attached between the ribs and are most prominent posteriorly towards the vertebral column. Anteriorly, at the costochondral junction, they are replaced by a membrane which attaches to the sternum. The direction of the muscle fibres is the same as that of the fingers inserted into the front pockets of the pants i.e. posterosuperiorly to anteroinferiorly. To see why contraction of the external intercostals causes the ribs to raise, consider the following. Each rib acts as a lever whose fulcrum is the vertebra. The muscle fiber is attached closer to the fulcrum on the lower rib than on the upper rib. The only way for the distance between the attachments to all of the ribs to shorten is for the ribs to rotate upwards. Thus the muscle's contraction causes rotating around the fulcrum which raises the ribs and the sternum. An excellent discussion of this phenomenon can be found in Dickson and Maue-Dickson (1982).

The raising of the ribs in itself increases the size of the thoracic cavity. This is because the ribs start out sloping downward so that lifting the sides causes them to extend farther in a lateral direction. This has been described as a "bucket handle" motion - to understand this analogy, imagine a bucket inside a balloon. If the handle is raised, the balloon must draw in air because its surface will be stretched away from the top of the bucket and the volume will be increased. In the same way, the raising of the ribs which start out sloped downward increases the distance across the thoracic region and increases the volume of the thoracic cavity.

The enlargement of the thoracic cavity during inspiration results in a decrease in the pleural pressure. The pleural pressure is the pressure present between the parietal pleura, adherent to the thoracic wall, and the visceral pleura, adherent to the lungs. When the pleural pressure decreases sufficiently below the atmospheric pressure to overcome the resistance of the lung tissue to being stretched, the lungs expand. Schematically it is like a balloon being filled by suction from the surrounding cavity.

When the inspiratory forces are removed, the lungs collapse back to their resting state. Normal expiration is entirely passive. The more the lungs are inflated, the greater their tendency to return to the resting position. This restoring force is known as the elastic recoil of the lungs. The relaxation pressure is the air pressure which would be measured inside the inflated lungs if the intercostals were relaxed and the flow of air out of the lungs were impeded.

In speech, the task is to produce a relatively constant positive air pressure in the lungs, despite the varying relaxation pressure. During normal conversation, this is achieved by the expiratory action of the internal intercostal muscles. Usually these are the *only* respiratory muscles active in quiet speech. The internal intercostal muscles are situated deep to the external intercostal muscles and their muscle fibers run perpendicular to those of the external intercostals i.e. posteroinferiorly to anterosuperiorly. This roughly perpendicular direction results in the ribs moving downward when the internal intercostals contract, thus forcing air out. After a large inspiration, the external intercostals and the diaphragm may become active in speech by counteracting the large relaxation pressure. Towards the end of a long utterance, the rectus abdominis muscle and the external obliques may assist the internal intercostals in pushing out air.

Bearing all this in mind, the following anatomical structures should at least be observed during a first dissection: the external and internal intercostal muscles, the ribs, the diaphragm, the external oblique muscles, the rectus abdominis muscle, the lungs within the pleura, and the trachea. As many measurements of subglottal pressure during speech are inferred from pressures recorded in the esophagus, its anatomical relationship with the trachea should also be noted.

Students should refer to Kahane and Folkins (1984), figures 2-1 to 2-23.

Dissection

With the cadaver lying on its back, begin by making a skin incision from the jugular notch in the midline, along the clavicle and out towards the arm. (see Figure 1.2) Next, make a midline incision from the jugular notch down to the cut edge of the torso. If a complete cadaver is used, continue the incision to within an inch below the umbilicus; a further incision will have to be made from this point out laterally to the side of the abdomen.

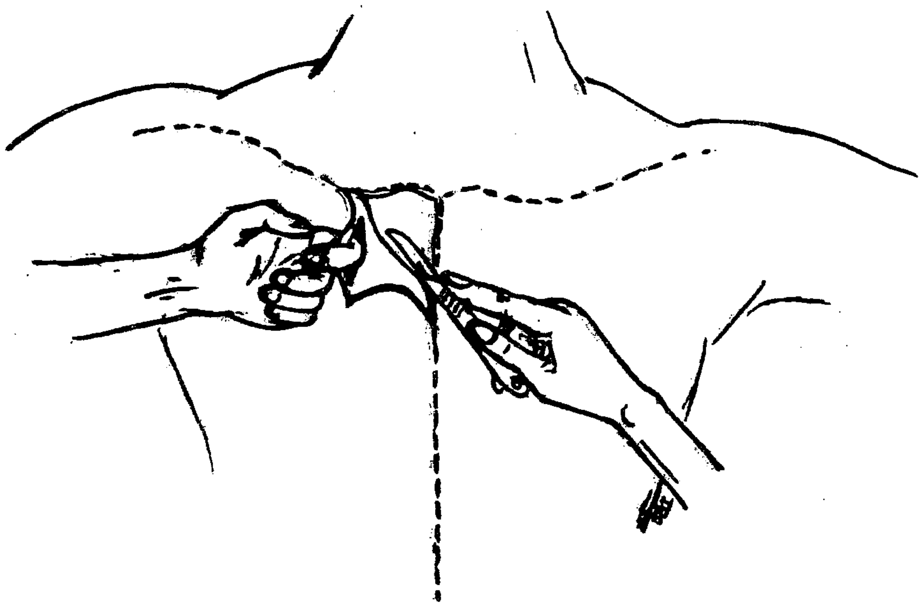

Figure 1.2. Skin incisions for the first dissection.

Beginning at the jugular notch, peel away the skin. This can best be done by reflecting a corner of the skin and making a small incision lateral to the corner in order to insert a finger. By pulling on this flap with the flexed inserted finger, the skin can be separated from the underlying fascia with a sharp scalpel. Pull on the skin hard, with the scalpel blade aimed upward to avoid damage to the underlying musculature as in Figure 1.2. The complete rectangle of skin from the clavicle down to the inferior edge of the torso (or the inferior incision line) should be reflected laterally. Underlying fatty tissue should be scraped or picked away by using scalpel and forceps, until all muscles are revealed.

Identify the pectoralis major muscle and note its medial attachments along the clavicle, the sternum and the ribs (Figure 1.3). Its lateral attachment is on the upper arm. Starting from the latter, insert a probe under the pectoralis major and lift it away from all underlying structures. Cut the muscle along its medial and inferior attachments and reflect it towards the arm . This should expose the pectoralis minor which is attached anteriorly to ribs 3, 4 and 5. Detach this muscle from its insertions into the ribs and reflect it towards the shoulder. Locate the external intercostal muscles between each rib (Figure 1.4). Anteriorly, they are particularly noticeable in an area located laterally and deep to the pectoralis minor. Note that the fibers run superolaterally to inferomedially and do not extend to the midline. Near the junction between costal cartilage and bony rib, they give way to the external intercostal membrane, the fibers of which run in the same direction as the muscle fibers.

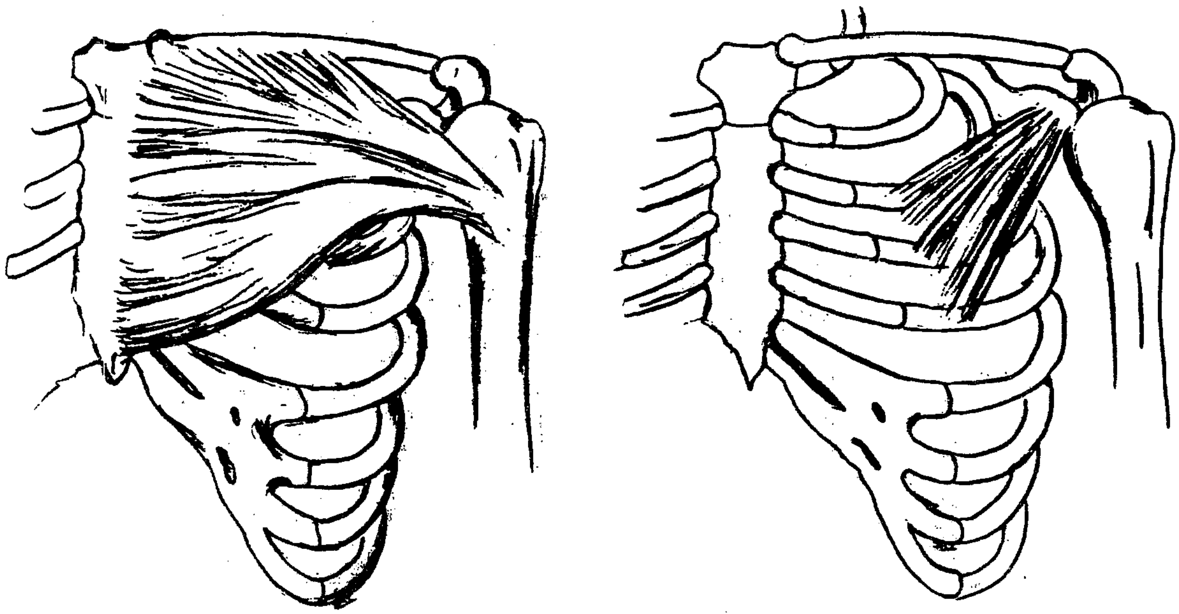

Figure 1.3. Pectoralis major (left) and minor (right). Cut pectoralis major away from the sternum and lift it away, revealing pectoralis minor.

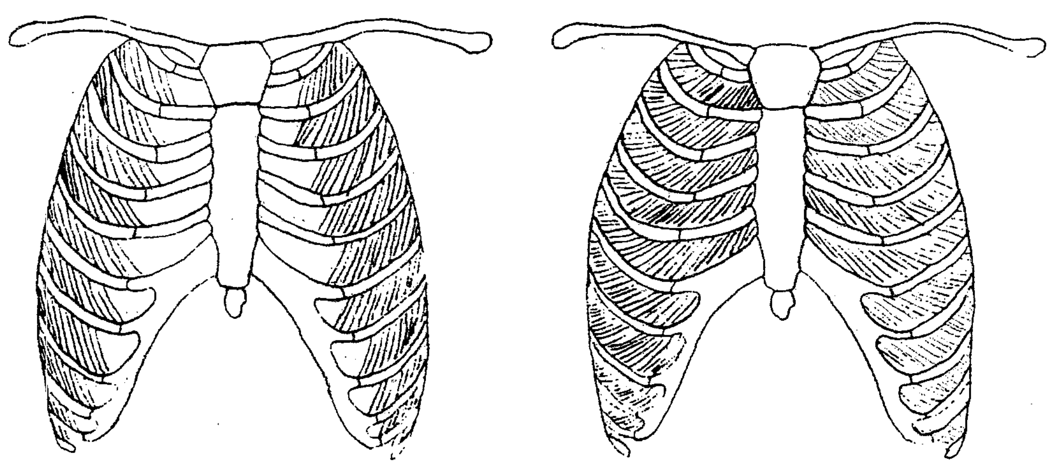

Figure 1.4. The direction and extent of external and internal intercostal muscle fibers. External intercostals, which are involved in lifting the rib cage and thus causing inspiration, are shown on the left of the figure. Internal intercostals (right) cause controlled expiration (as in egressive pulmonic airflow) by lowering and contracting the rib cage.

By carefully peeling the external intercostal membrane upwards, the underlying internal intercostal muscle is revealed. These muscles are most prominent near the midline, the inferior part of the thoracic cage (around ribs 9 and 10). Note that the fibers run superomedially to inferolaterally. By inserting a probe in the plane between external intercostals and internal intercostals, the former can be cut along one rib and reflected upwards (Figure 1.5). This procedure should reveal the internal intercostal muscles more clearly.

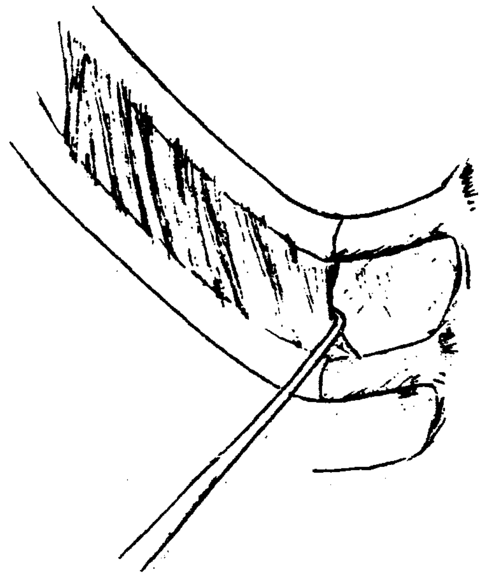

Figure 1.5. Reflecting the external intercostals.

Near the midline, notice the rectus abdominis muscles (Figure 1.6), which attach to the costal margin and can extend superiorly as high as the posterior aspect of the fifth costal cartilage. Lateral to these muscles, the external oblique muscles (Figure 1.7) sweep downward and medially from the costal margin. Their fibers run in the same direction as those of the external intercostal muscles. By reflecting the external oblique, fibers of the internal oblique muscle can be seen sweeping upward and medially. If only a torso is available for dissection, these abdominal muscles will be sectioned close to their attachments to the costal margin.

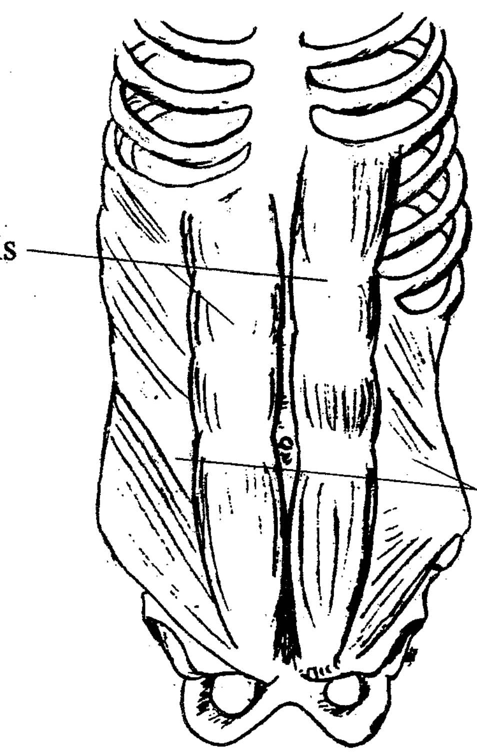

Figure 1.6. Rectus abdominis and external oblique abdominis.

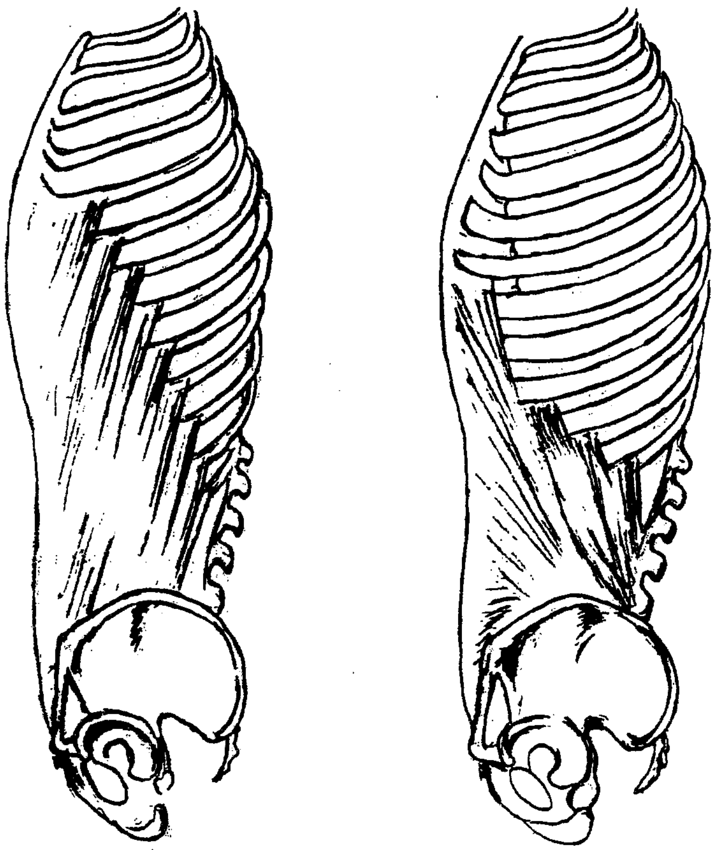

Figure 1.7. External and internal oblique abdominis. Externals on the left of figure, internals on right. Anterior is toward the left of this diagram.

Opening the thoracic cavity

Using a bone saw, cut through the upper part of the sternum below the first rib, as indicated in Figure 1.8. Saw or break the ribs laterally on both sides.

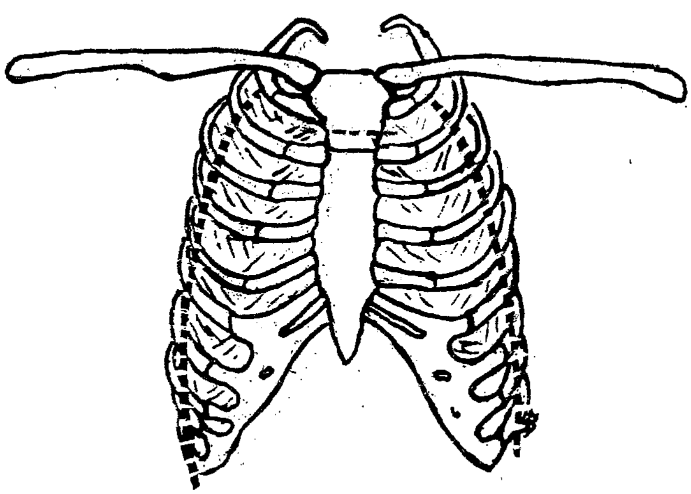

Figure 1.8. Skeletal cuts for opening the thoracic cavity. Dotted lines indicate approximate position of cuts through ribs 2 - 10 and across the manubrium (upper portion of the sternum).

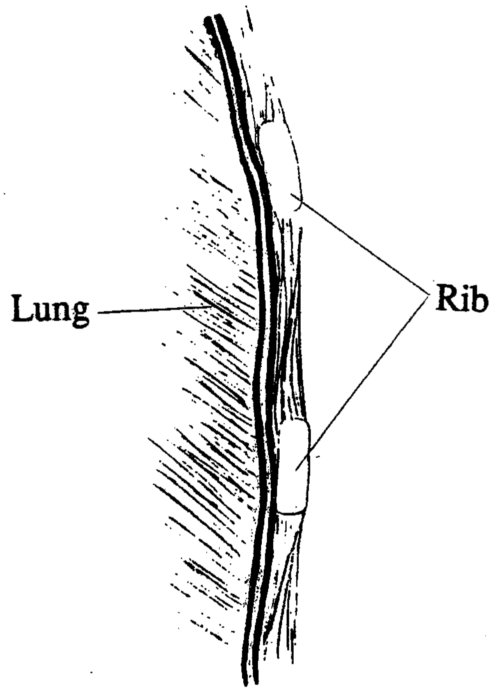

Figure 1.9. Schematic of the visceral and parietal pleurae, showing relation of pleural layers to inner thorax (lung) and outer thorax (rib cage). The visceral pleura is the inner layer, the parietal pleura the outer layer.

Inside the rib-cage there is a membranous layer forming the pleura. There are two parts to the pleura, the outer or parietal part being attached to the interior of the rib-cage, and the inner, visceral, part being firmly adherent to the lungs.

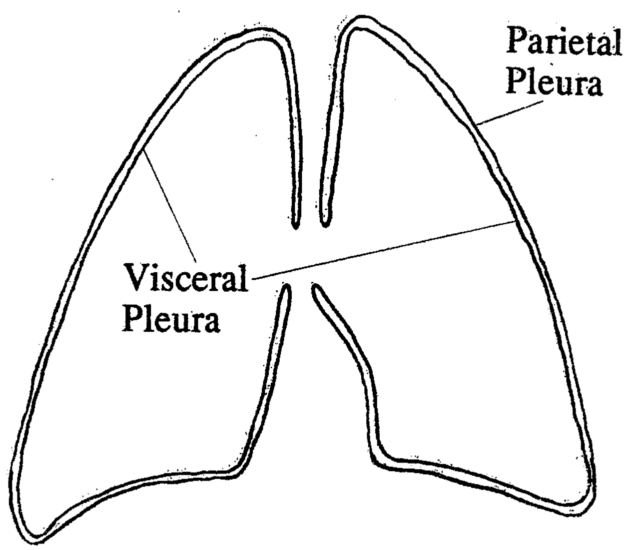

Figure 1.10. A schematized coronal section of the pleural layers, showing them as a single continuous membrane.

It is important to realize that these two layers are actually part of a single sheet, folded on itself. Lift the lower portion of the manubrium and ribs two through twelve downward using your fingers to separate the parietal pleura from the visceral pleura . Examine the reflected part of the rib-cage from the interior, noting the internal intercostals and transversus thoracic group of muscles which attach some of the ribs to the sternum.

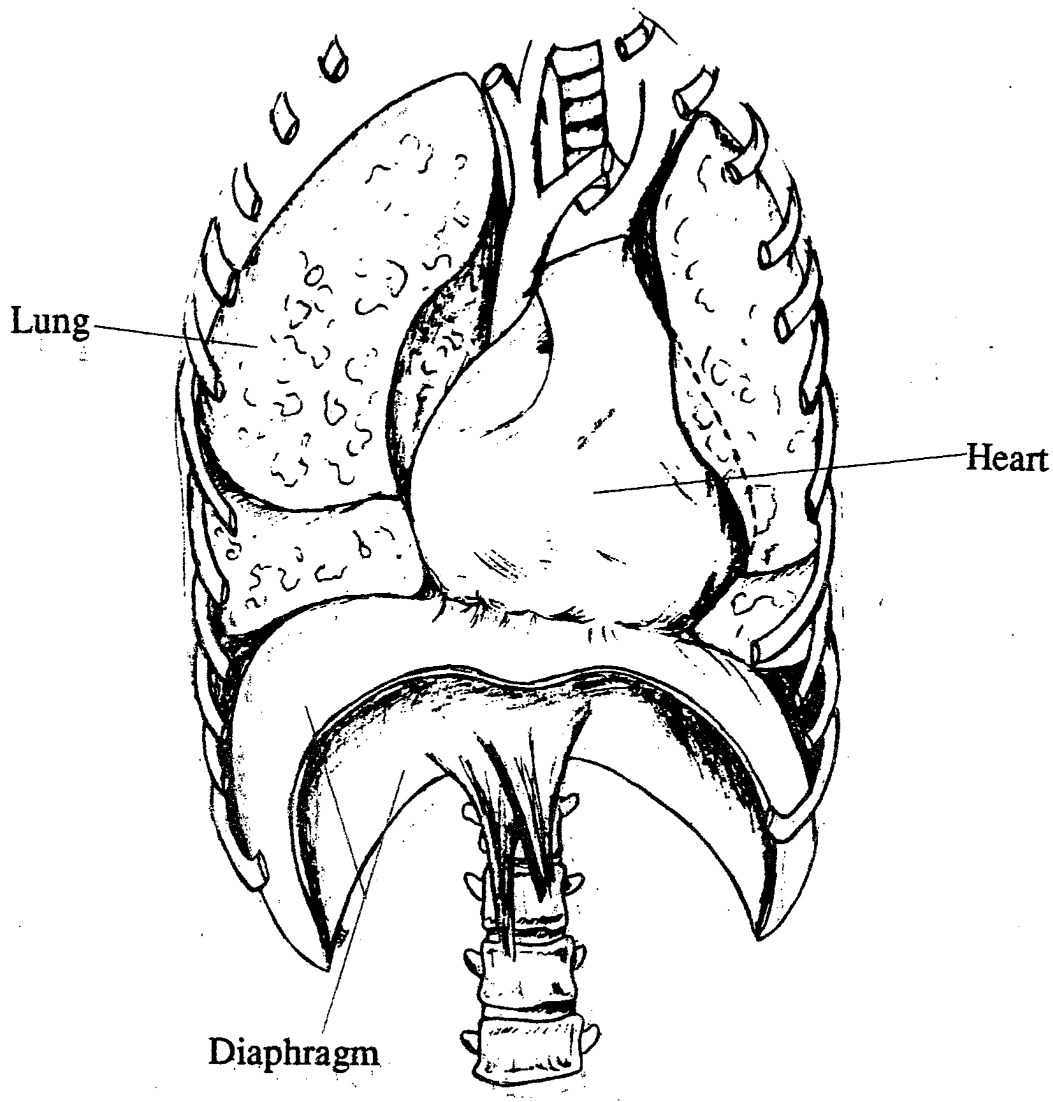

Figure 1.11. Structures of the thoracic cavity. Note the heart within the pericardial sac.

Locate the left and right lungs. The right lung has three lobes, where the left lung has two. The left lung is smaller than the right lung additionally because of the heart (within the pericardial sac), which lies slightly to the left of the midline.

Find the pericardial sac between the left and right lung (Figure 1.11). This sac is a connective tissue sheath, actually an extension of the visceral pleura, which envelops the heart. In some cadavers the pericardial sac may be covered with quite a large amount of fat which may have to be removed. Slit the pericardial sac longitudinally. Make two more vertical incisions across the longitudinal incision to form the shape of a capital I, and reflect the two flaps thus formed laterally. The heart should now be visible inside the sac. Find the ascending aorta and pulmonary trunk and with a sharp scalpel cut them both at their junction with the heart (incision A on Figure 1.12). Slipping a hand under and around the posterior aspect of the heart, palpate and cut all of the major connecting blood vessels attached to the heart (incisions B and C on Figure 1.12). Palpate the undersurface of the heart where it sits on the top of the diaphragm. Find the inferior vena cava and cut it where it joins the heart (incision D on Figure 1.12). Lift the heart out, exposing the trachea bifurcating and connecting to each of the lungs.

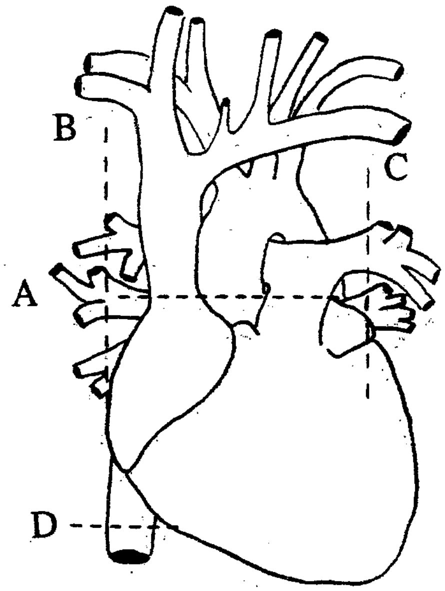

Figure 1.12. The heart and its connecting arteries.

To remove the lungs, slip a hand down under and around the lungs in the thoracic cavity. Near the midline you will find the bronchus and pulmonary arteries and veins which attach the lungs to the heart. Cut the bronchus, the pulmonary artery, and the veins at the root of each lung. Run a finger around and behind each lung, separating adherent layers of visceral and parietal pleurae and remove the lung from the thoracic cavity.

Because the heart is on the left, the right lung is larger than the left lung and it is divided into a superior, a middle and an inferior lobe by the oblique and horizontal fissures. The left lung is divided by the oblique fissure into a superior and an inferior lobe. Observe that the visceral pleura extends into the interlobar clefts; notice the spongy consistency of the lungs. The appearance in the cadaver is most often midway between inflation and deflation. Study the root of the lungs where you will find the bronchus, the pulmonary artery and veins grouped together. This close relationship between the air ducts and the blood vessels is maintained deep into the substance of the lungs, to facilitate gas exchange. If time permits, dissect a lung by following a bronchus down its branching structure.

After removing the lungs, note the attachments of the diaphragm (Figure 1.13). Anteriorly, it is comprised of layers of muscle which originate on the superior edges of the anterior ends of ribs 7 to 12. These layers rise and converge together with fibers running posteriorly from the sternum all joining to the central tendon. Posteriorly, it arises in two strong tendons (crura); the right one attaches to lumbar vertebrae 1, 2 and 3 whereas the left one attaches only to lumbar vertebrae 1 and 2. From these origins, the diaphragm curves superiorly into right and left domes. Its central tendon is firmly attached to the fibrous pericardium.

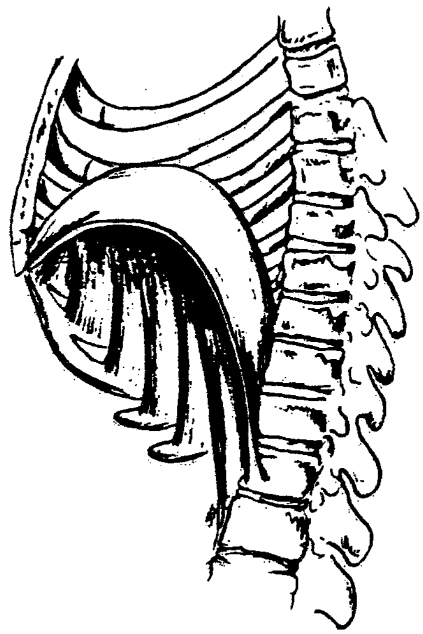

Figure 1.13. **The diaphragm and its attachments.**

Notice that the diaphragm is pierced by three structures: the aorta at the level of thoracic vertebra 12 (T12), the esophagus at T10 and the inferior vena cava at T8. Remove the contents of the abdominal cavity, so that the domes of the diaphragm can be observed from underneath.

Remove the vessels in front of the trachea and examine the relationship of this air duct to the esophagus. Identify the individual tracheal rings, noting that they are actually C-shaped cartilages bound posteriorly by a sheet of smooth muscle called the trachealis. The trachea divides into two bronchi which are composed of imperfect cartilaginous rings bound together by fibroelastic and smooth muscle tissue.

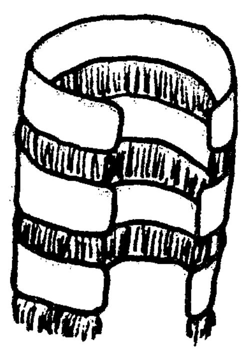

Figure 1.14. Schematic of the tracheal rings, showing the C-shaped 'open ring' structure.

Posterior to the pericardium, trace the thoracic course of the esophagus to the upper part of the stomach inferiorly. Superiorly, it lies directly against the trachealis muscle thus enabling the approximation of tracheal air pressure by measurement of the esophageal air pressure.

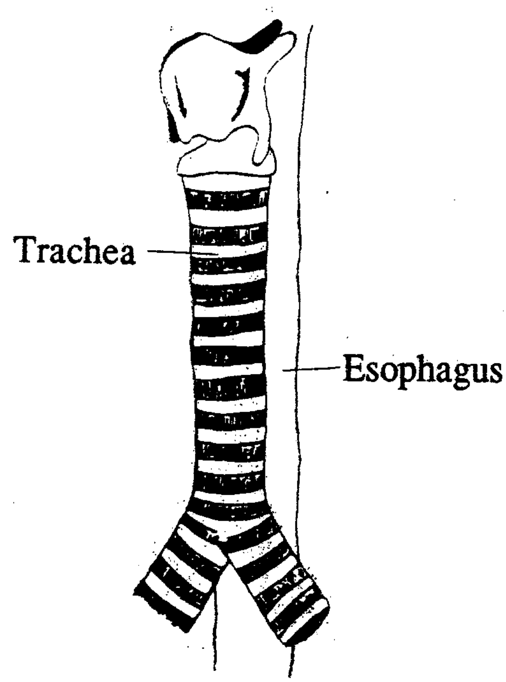

Figure 1.15. A schematized diagram showing the relation of the trachea and esophagus.

2. Muscles of Lip Movement

The principal object of the next dissection is to observe the muscles that are used for moving the lips. From a phonetic point of view there are three major movements of the lips:

(a) *Rounding-spreading* (the corners of the lips are drawn together or pulled apart). Rounding is achieved largely by the action of the orbicularis oris muscle, which is a sphincter muscle. It acts in opposition to the zygomaticus major (and minor), the buccinator, and the risorius muscles, all of which are dilator muscles.

(b) *Protrusion* (the lips are pushed forward, making the vocal tract longer). Protrusion involves the lower lip more than the upper. For the lower lip, the mentalis and the depressor labii oris probably play the major roles. The turning of the upper lip outward is achieved by the levator labii superioris, and the zygomaticus minor.

(c) *(Vertical) Compression* (the lips come together, mainly by the lower lip being raised). Vertical compression occurs without lip rounding. It is achieved by simultaneous actions of the inferior part of the orbicularis oris muscle and the mentalis muscle. These actions may be accompanied by movements of the mandible, which we will examine later.

The major anatomical structure to observe in this dissection is the modiolus, the point near the corner of the lip where a number of muscles come together. The muscles to be identified are illustrated in Kahane and Folkins (1984), chapter 11. Note in particular their figures 11-3, 11-4, 11-5 and 11-11, all of which contain photographs of excellent dissections that students should try to replicate. Their figure 11-7, showing the way in which the facial muscles blend into one another, is a salutary reminder of the difficulties of achieving dissections showing the separate muscles.

Dissection

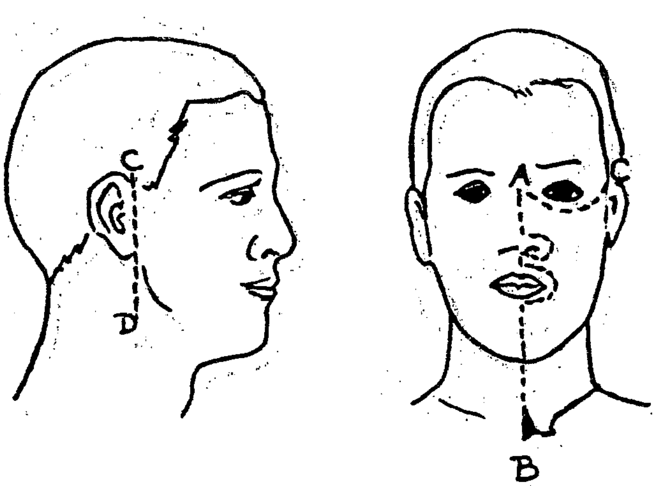

Figure 2.1. Skin incisions required for dissection of the facial muscles.

Make skin incisions as shown in Figure 2.1.

AB in the mid-line from the nose down to the previously cut skin at the level of the clavicle, but going round the nostrils and lips; AC from the mid-line to a point just in front of the ear, going below the eye (the orbital margins); CD laterally to below the angle of the mandible, where the skin has been previously cut.

Reflect the skin, beginning at point B and working upwards. In the area of the cheek there will probably be considerable subcutaneous fat, which makes the removal of the skin simple. But nearer the lips it is more difficult to separate the skin from the muscles, as the muscles are directly attached to the skin. In all cases point the blade of the scalpel outwards, towards the skin, so as to avoid damaging the muscles immediately below.

Begin the location of the muscles by removing the parotid gland and the fatty pads above the zygomaticus major muscle. Note the seventh (facial) nerve, which goes through the parotid gland.

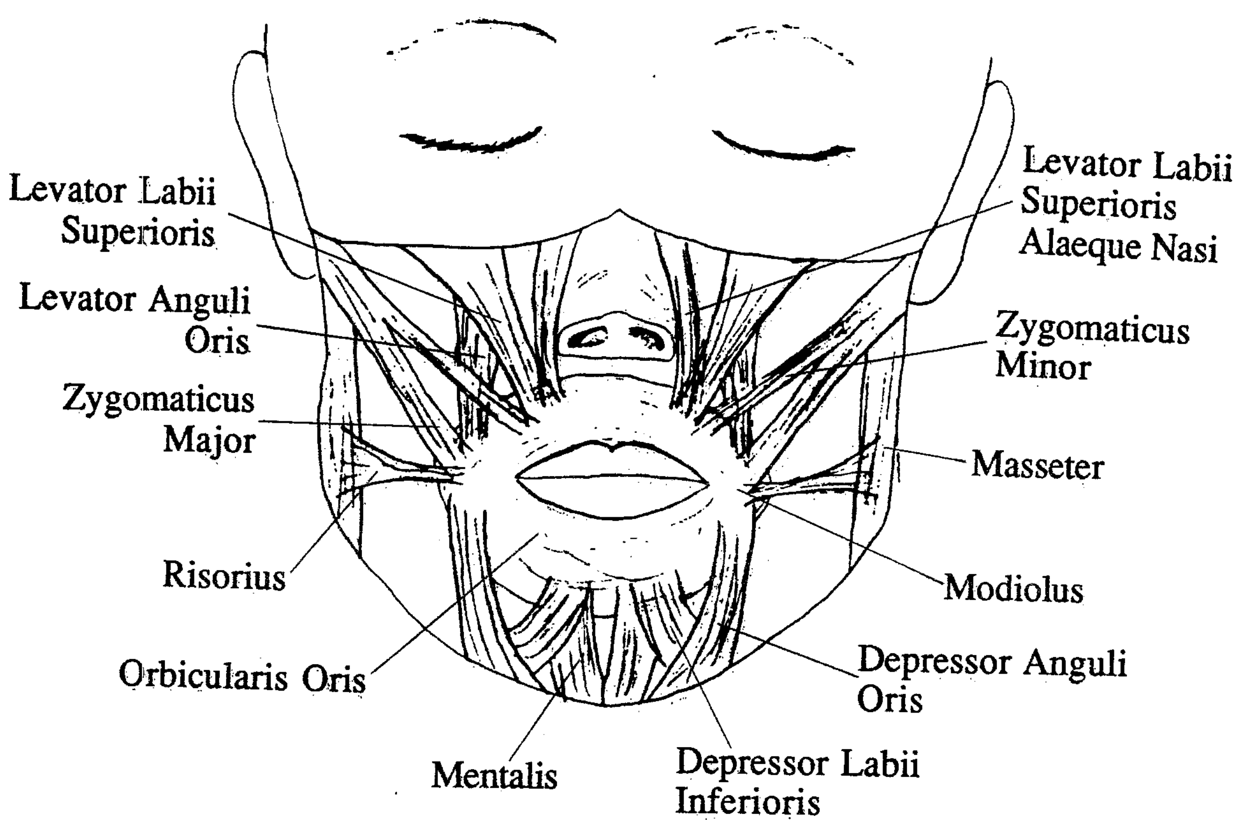

Figure 2.2. Superficial muscles of the face.

Follow the zygomaticus major muscle from its origin on the zygomatic bone down to its insertion into the modiolus near the corner of the lip, as shown in Figure 2.2.

Now find the other muscles that join at the modiolus, beginning with the levator anguli oris muscle, close to the zygomaticus major, and the risorius muscle. The risorius may be very thin or even absent altogether. The fibers of the buccinator also insert into the modiolus. This muscle is deep to the zygomaticus major, and will be apparent after all the fatty pads of the cheeks have been removed.

Medially, immediately below the nose, the skin above the upper lip is more difficult to remove. Below it lies the superior portion of the orbicularis oris, the levator labii superioris, the zygomaticus minor and the levator labii superioris alaeque nasi. These last three muscles can be used to raise, and (to a small extent) to protrude the upper lip.

Continuing with the examination of the modiolus, locate the depressor anguli oris, and the fibers of the orbicularis oris that interdigitate with the fibers of the other muscles in this area. Altogether six muscles come together at the modiolus: (1) the orbicularis oris (both the superior and inferior parts), (2) the zygomaticus major, (3) the levator anguli oris, (4) the risorius, (5) the buccinator (a muscle running in the same direction, but deep to, risorius), and (6) the depressor anguli oris. The movements of this point are central to the actions of lip rounding and lip spreading.

The skin below the lip is also difficult to remove, as it, too, is closely connected to the orbicularis oris. Note how the fibers of this muscle surround the lips, enabling it to have a kind of purse string action.

The protrusion of the lower lip is achieved largely by the depressor labii inferioris. Locate the origin of this muscle on the mandible, and its insertion into the orbicularis oris. The other muscle involved in protruding the lips is the mentalis. To find this muscle it is best to cut in the mid-line below the lower lip to the mandible itself, thus splitting the fatty pad forming the chin . The mentalis will also be split and may be observed along the cross-section under the fatty pad

3. The Jaw and Related Structures

The position of the jaw is important in speech in that it considerably affects that of the tongue. In addition, proper positioning of the upper and lower front teeth (the incisors) is required for the pronunciation of sibilants such as [s]. Accordingly, in this dissection we will study the muscles responsible for raising the jaw. Jaw lowering will be considered in Section 4. The present dissection also provides an opportunity to locate some of the nerves involved in speech production.

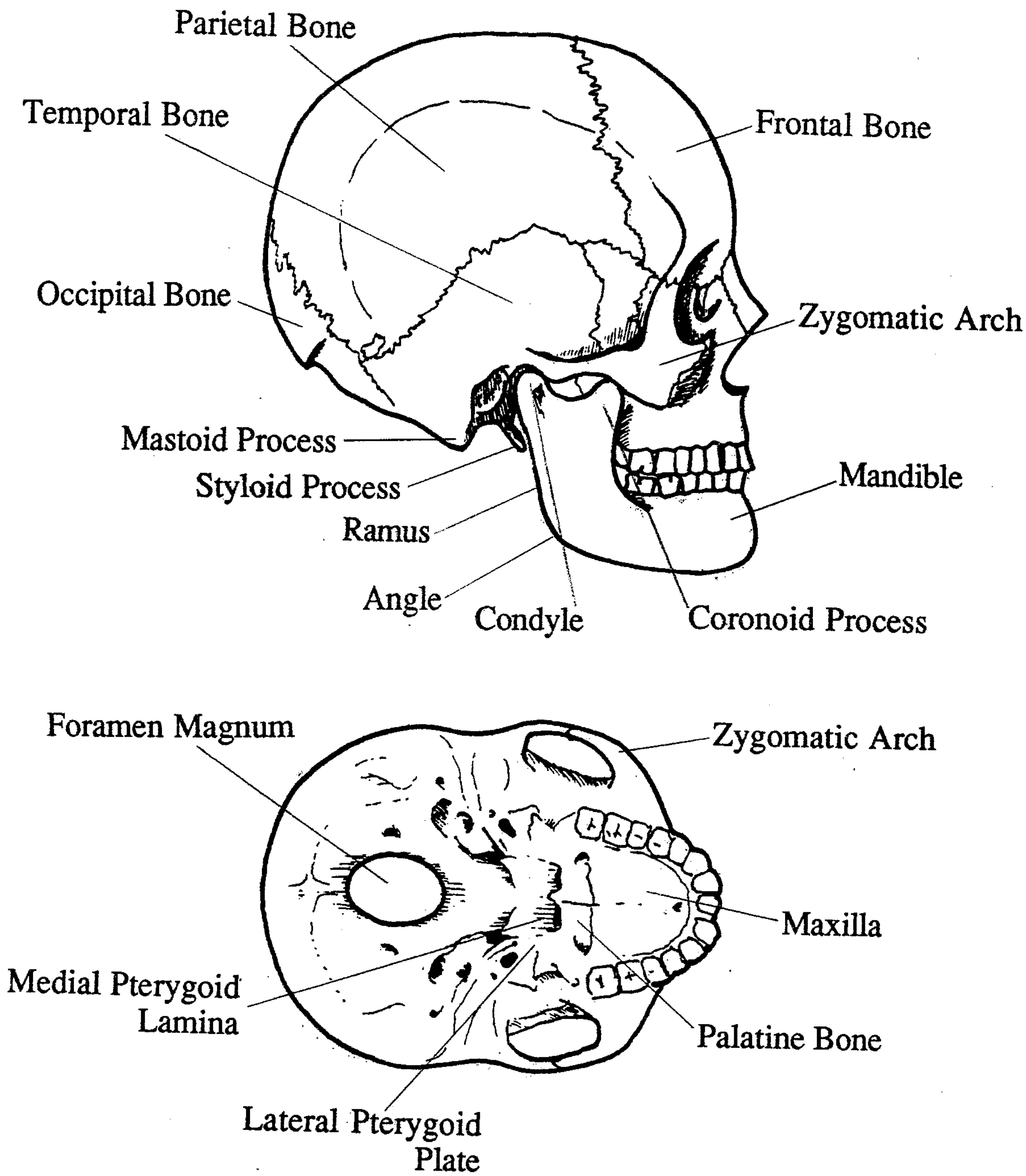

Figure 3.1. Landmarks of the skull.

In approaching structures of the deep face, it will be helpful to note a number of reference points on the exterior portions of the skull. Considering first a lateral view of the skull, useful landmarks on the mandible are the condyle, which forms part of the temporo-mandibular joint, the coronoid process, the ramus, and the angle, all of which are indicated in Figure 3.1. Additional important points of reference also represented there are the maxilla, the zygomatic arch, the temporal bone, the sphenoid bone, and the styloid process.

The muscles to be observed in this dissection are listed below along with their attachments and functions.

The masseter attaches to the zygomatic arch and to the ramus of the mandible. It closes the jaw by elevating and drawing forward the angle of the mandible. See Figure 3.2.

The buccinator lies deep to the masseter and is the muscle of the cheek-pouch. See Figure 3.2.

The temporalis arises from the temporal bone and attaches to the coronoid process of the mandible. The anterior two thirds of the temporalis muscle help to elevate the mandible. The posterior third retracts the mandible. This is the only muscle that retracts the mandible. See Figure 3.2.

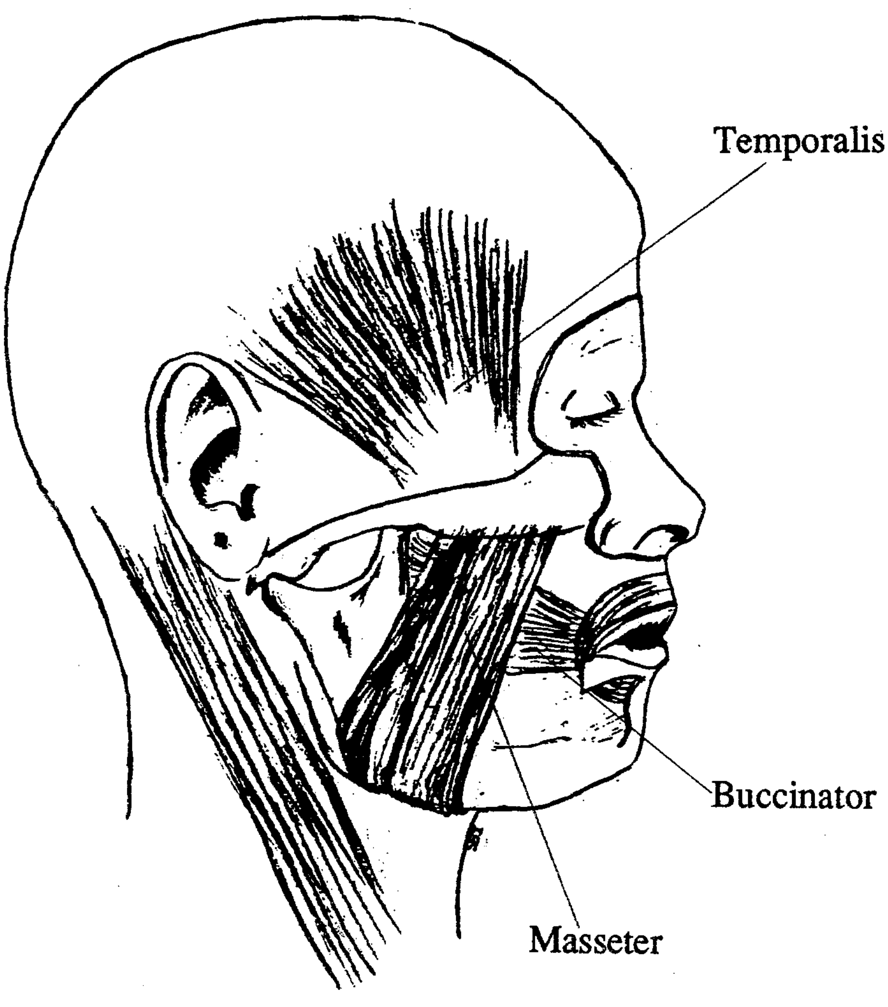

Figure 3.2. External muscles of jaw raising.

The lateral pterygoid muscle arises from two heads, one from the surface of the lateral pterygoid plate and one from the lateral portion of the greater wing of the sphenoid bone. It inserts into the pterygoid pit beneath the mandibular condyle (the head of the mandible). The lateral pterygoid muscle draws the mandible forward by drawing on the condyle. Medial pterygoid muscle (Figure 3.3), which arises from the medial surface of the lateral pterygoid plate (see Figure 3.1) and attaches to the medial side of the angle of the mandible. By pulling the angle of the mandible towards the lateral pterygoid, that is, superiorly, anteriorly and medially, it closes the mouth.

The following nerves will also be observed (see Figure 3.3).

The inferior alveolar nerve which is a branch of the posterior mandibular division of the trigeminal nerve. It innervates the teeth and also provides sensory innervation for the lower lip.

The lingual nerve, which is another branch of the posterior division of the mandibular branch of the fifth cranial nerve. It runs in front of the inferior alveolar nerve and supplies (among other things) the mucous membrane of the anterior two-thirds of the tongue.

The mylohyoid nerve, which is a branch of the inferior alveolar nerve. It innervates the mylohyoid muscle, and the anterior belly of the digastric muscle.

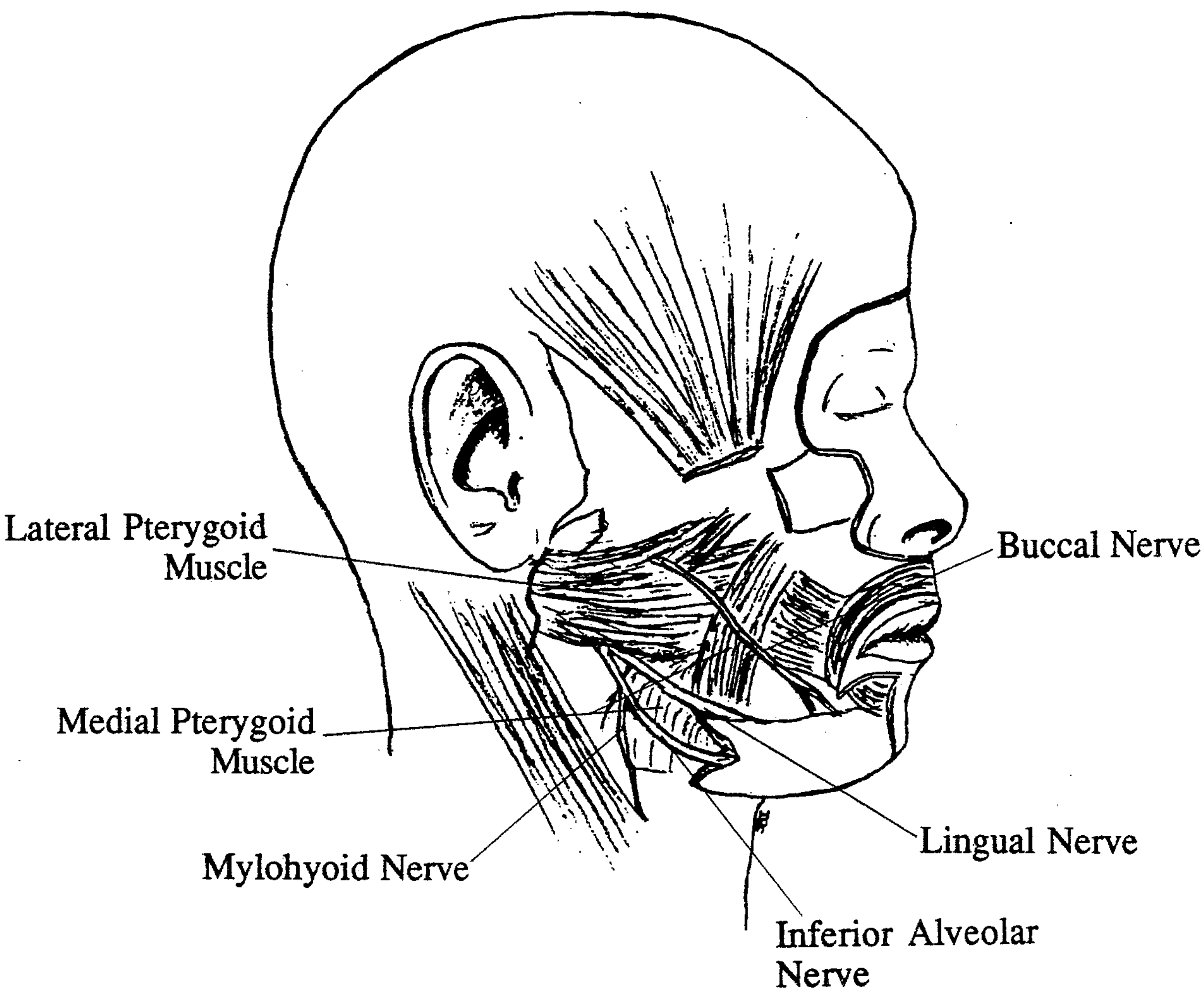

Figure 3.3. Other structures of the deep face.

The features of the skull discussed above are shown in Kahane and Folkins (1984) in figures such as 1-5, 1-6 and 1-9. Some of the muscles in this dissection are shown in their figures 10-9 and 10-10, though the views illustrated there differ from those described below because they followed different dissections.

Dissection.

Remove the skin above the zygomatic bone to reveal the temporalis muscle, cutting over the brow and pulling the skin off the upper portion of the skull. Clear away the fascia and fat from around the zygomaticus bone. This will make the bone easier to saw through later on.

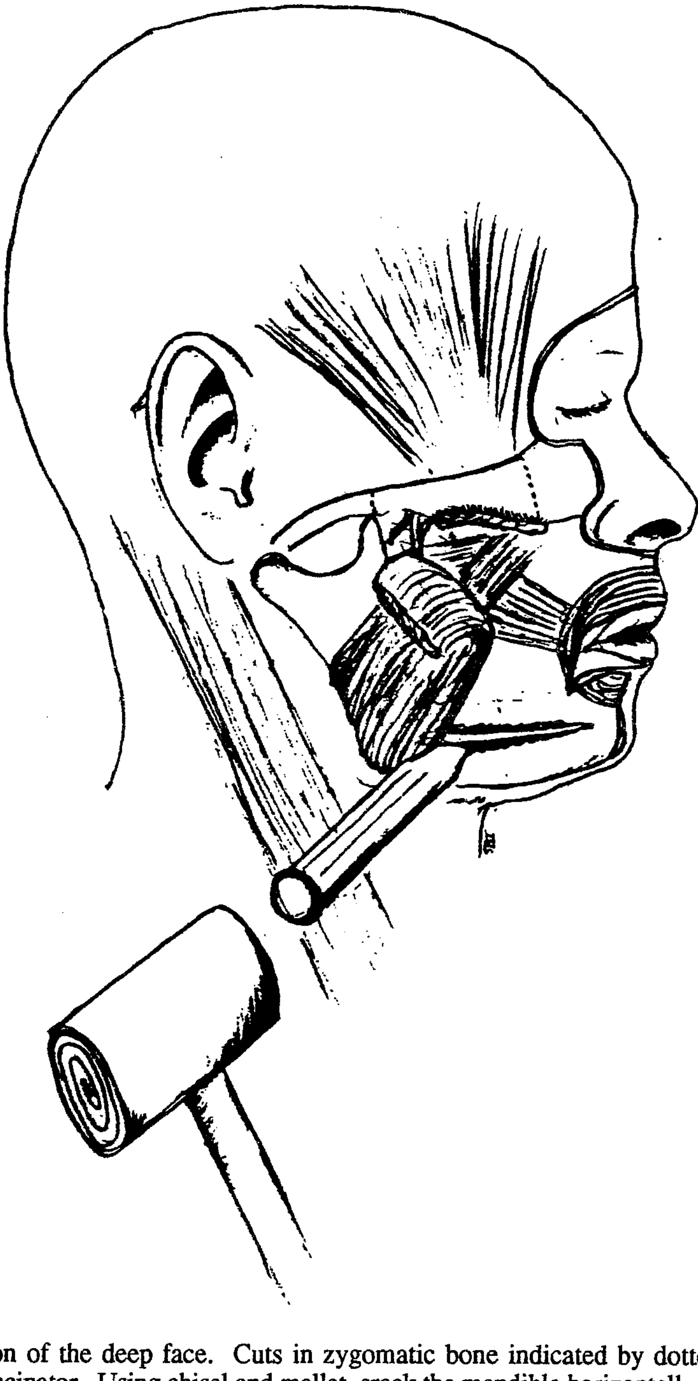

Figure 3.4. Dissection of the deep face. Cuts in zygomatic bone indicated by dotted lines. Masseter reflected, exposing buccinator. Using chisel and mallet, crack the mandible horizontally.

Reflect the masseter down by cutting the muscle along the inferior border of the zygomatic arch. Examine the underside of the muscle and observe the masseteric nerve, which runs superior to the mandibular notch, the recessed area between the condyle and the coronoid process of the mandible. Also find the masseteric artery, which runs between the intermediate and superficial tendons of the masseter.

Make the following cuts, as indicated in Figure 3.4. Use a bone saw to section the zygomatic arch vertically just anterior to the condyle of the mandible, and make another cut about 3 cm anterior to the first. Remove the cut piece of the mandible and observe the temporal fascia. Notice the attachment of this tissue in the temporal fossa, then section and reflect the temporal fascia. The temporalis muscle is deep to it; it originates in the temporal fossa and inserts into the anterior border of the coronoid process and the anterior border of the ramus of the mandible.

Section the temporalis muscle where it inserts into the anterior border of the ramus and reflect both it and the coronoid process upward. Pull the masseter away and cut it from the mandible. Use a chisel to crack the mandible horizontally just anterior to the angle (have another person keep the head steady by pushing against the opposite side of the jaw). Pull away cracked pieces of bone to reveal the inferior alveolar nerve that runs inside the horizontal portion of the mandible. Continue chiseling away the mandible bone posterior to this cut, taking care not to break the inferior alveolar nerve. As you pull away the pieces of bone, you should observe the medial pterygoid intact, deep to where the mandible was. Note that it will be harder to do the second side since the whole jaw is loose after the sectioning. The person pushing against the opposite side should be careful not to be cut by jagged bone. The inferior alveolar nerve runs along the lateral aspect of the medial pterygoid muscle, and enters the mandibular foramen after sending off a branch, the mylohyoid nerve. The mylohyoid nerve runs along the mylohyoid groove on the medial surface of the mandible.

Follow the mylohyoid nerve medially from the mandibular foramen and find the lingual nerve. Refer to Figure 3.3 for the relative location of these nerves. Examination of this region will be facilitated by removal of excess fat and fascia; do so with the usual caution. When the area is cleared, locate the buccal nerve, a fairly thick nerve medial to the lingual nerve.

Note how the lateral pterygoid muscle serves to pull the jaw forward by pulling on the condyle. Once this has been understood, section the muscle near its insertion at the condyle of the mandible, and then near its origin at the lateral aspect of the lateral pterygoid plate. Remove this muscle. Next, remove the condyle from surrounding tissue. Be careful to preserve the inferior alveolar and lingual nerves; the goal is to trace them up to their exit through the foramen ovale.

4. The Strap Muscles of the Neck

The neck can be thought of as a column or pipe with several smaller pipes inside it. Each pipe is a wall of connective tissue; most structures run superiorly and inferiorly inside one particular space between these walls of connective tissue. The outermost column is, of course, the skin. Anteriorly, immediately beneath the skin lies the platysma (this muscle will have been exposed by the peeling of the skin in the dissection of the facial regions).

The strap muscles of the neck lie deep to the platysma muscle.

The structures to observe are (1) the strap muscles which control the positioning of the larynx and the nerves responsible for their motor innervation, (2) the larynx and its motor nerves, and (3) the muscles forming the floor of the oral cavity and their motor nerves. It is convenient to dissect these structures from the outside and work inwards, thus starting with the strap muscles and then proceeding to the deeper structures.

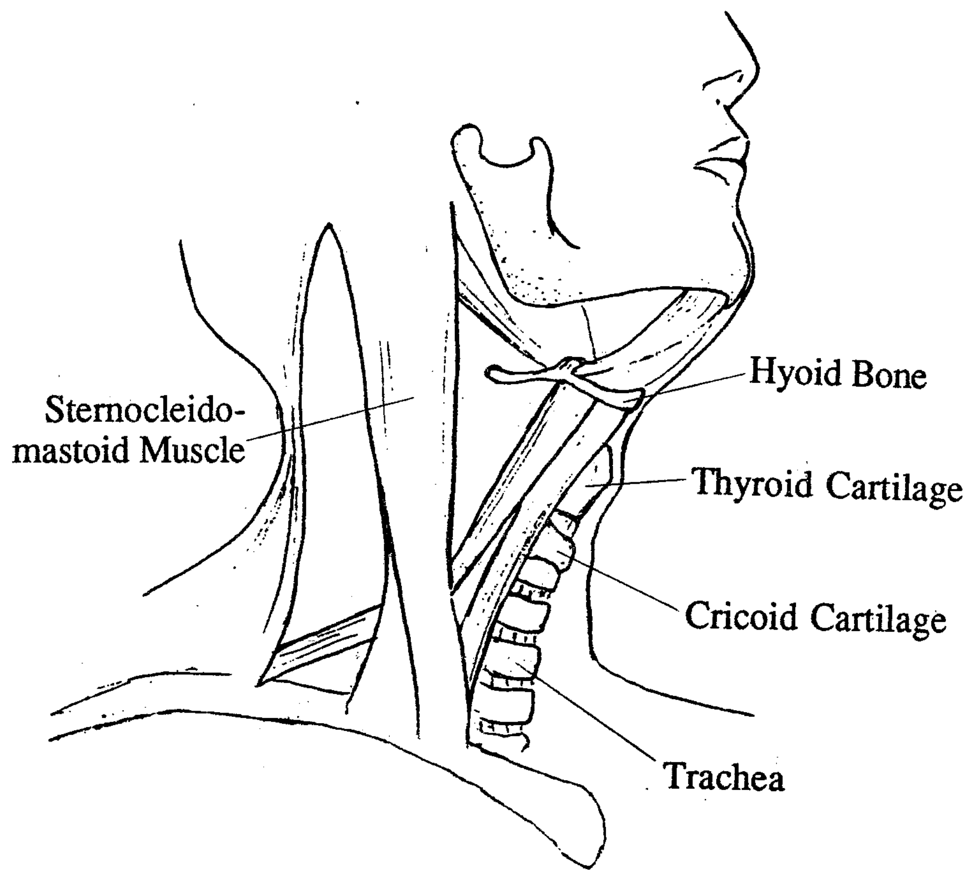

Figure 4.1. Landmarks of the neck.

The muscles important to speech production are those which control the positioning of the hyoid bone. Before beginning the dissection, note the following bony and cartilaginous landmarks which you should be able to feel on your own neck. Its worth gaining a good understanding of these landmarks before pursuing the dissection because they will be used to locate the muscles in the anterior region of the neck. The relative positioning of these landmarks and their relation to the strap muscles of the neck is illustrated in Figure 4.1 and this should be studied.

1) The hyoid bone lies between the floor of the mouth and the upper end of the neck. Palpate this bone with a thumb and finger on either side of your neck, close to the mandible. You should be able to feel the movements of the cornua of the hyoid bone when you swallow. Try saying the vowel sequence [i-a]; note the higher position of the hyoid bone for the higher vowel. Is there any movement when you say a vowel at different pitches? Usually, the higher the pitch, the higher the position of the hyoid bone, though individuals differ in this respect.

2) The thyroid cartilage, which is the large cartilage of the larynx. At the midline locate the laryngeal prominence (or Adam's apple). This will be larger in men than in women. When you swallow, this cartilage will also move. Again, attempt to say the vowel sequence [i-a] while holding your thyroid cartilage. There will probably be less movement than that of the hyoid bone, but there will probably be a larger movement when you say a vowel at different pitches (this may not be true for trained singers).

3) The cricoid cartilage, which is inferior to the thyroid cartilage and superior to the first tracheal ring. Its movements are very similar to those of the thyroid cartilage.

Begin the dissection by reflecting the skin from the front of the neck. The platysma is a very thin muscle and should be removed with the skin at this time. The sternocleidomastoid muscle runs from the skull just posterior to the angle of the mandible to the sternum. Find its attachment on the sternum and cut and reflect this muscle laterally.

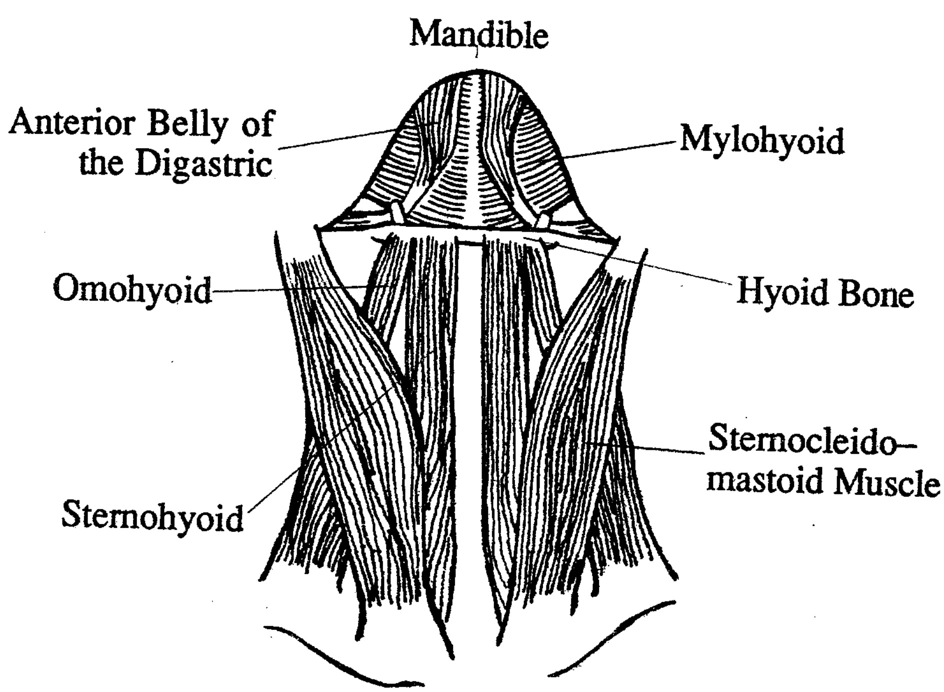

Figure 4.2. Anterior muscles of the neck.

Once you have removed this overlying layer locate the strap muscles of the neck (Figure 4.2). There are four primary strap muscles. These muscles are located in two layers beneath the platysma muscle. The superficial layer consists of two muscles, (1) sternohyoid, and (2) omohyoid. The sternohyoid attaches inferiorly to the posterior aspect of the sternoclavicular joint and the manubrium and superiorly to the hyoid bone. Lateral to the sternohyoid is the omohyoid muscle, which runs from the hyoid bone , through a connective tissue hook to the scapula. These two muscles cover the deeper layer of strap muscles.

Now that you have observed the two superficial strap muscles, cut and reflect them to reveal the two deep strap muscles (Figure 4.3). Cut and reflect the sternothyroid muscle to reveal the two deep strap muscles, (1) sternothyroid, and (2) thyrohyoid (Figure 4.3, right). The sternothyroid depresses the larynx. The thyrohyoid attaches inferiorly to the thyroid and superiorly to the hyoid bone.

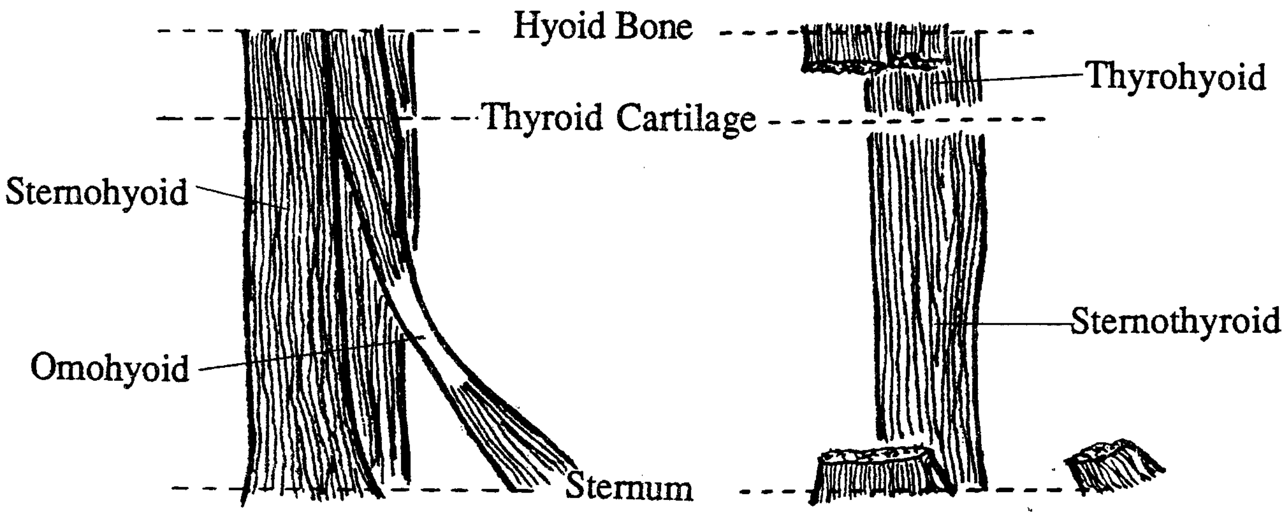

Figure 4.3. Sectioning the strap muscles. In this schematic figure, "Hyoid Bone", "Thyroid Cartilage" and "Sternum" indicate the level of those structures with respect to the muscles. The muscles are shown as the appear on the right side of the neck before sectioning (left) and after (right).

Next, locate the digastric muscle (Figure 4.2). This muscle consists of two separate bellies connected together by a tendon. The anterior belly of the digastric attaches to the mandible anteriorly and runs to the hyoid bone where it passes through a fibrous sling. The portion of the digastric which passes through the sling is not muscle but tendon. After passing through the sling, the muscle becomes the posterior belly of the digastric which attaches posteriorly to the medial surface of the mastoid prominence. Remember that the hyoid bone has a connective tissue sheath attached to it which the intermediate tendon of the digastric passes through. Thus there is no direct attachment of the digastric onto the hyoid bone. The digastric muscle is used in conjunction with the infrahyoid or strap muscles to lower the jaw. Both the digastric and the strap muscles contract. The strap muscles counteract the upward force exerted by the digastric and hold the hyoid bone in place. The digastric shortens, pulling the jaw down.

Next, locate the mylohyoid muscle. This muscle forms the floor of the oral cavity. Always keep in mind your orientation. Remember, that you are observing this muscle from below. Above this muscle lies the oral cavity and the tongue. The mylohyoid arises from the inside of the mandible and inserts in a midline raphe (a seam-like ridge or furrow joining two different muscles) with the mylohyoid from the opposite side. The left and right mylohyoid muscles together form a sling which supports the body of the tongue. Contracting the mylohyoid will raise the tongue as a whole.

Section and reflect the sternothyroid muscle, thus revealing the thyroid gland. This gland consists of two pyramidal lobes joined together by a narrow strip anterior to tracheal rings 2, 3, and 4. Dissect carefully around the thyroid gland, disconnecting its vascular supply and removing it completely from the trachea. Now you have exposed the trachea, revealing its C-shaped cartilages, joined together by a fibrous elastic membrane. Superiorly, it is attached to the inferior border of the cricoid cartilage. Posteriorly, the gaps in the C-shaped cartilage are closed by smooth muscle, the trachealis muscle. The latter rests against the anterior wall of the esophagus. Between the trachea and esophagus, find the recurrent laryngeal nerve, a branch of the vagus nerve which supplies motor innervation to the intrinsic muscle of the larynx. This nerve is traveling upward toward the larynx after it has descended toward the heart. The left recurrent laryngeal nerve loops around the aorta, while the right hooks around the right subclavian artery.

5. The Brain and the Cranial Nerves

Caution: Wear a double set of gloves when handling brain and nervous tissue. There are viruses which live in the central nervous system and which are not killed by formaldehyde or other fixatives. These can be transmitted through cuts or microscopic cracks in your skin. If you cut or puncture your gloves, change them immediately.

Full dissection of the brain is beyond the scope of this manual. We will, however, note the major structures that are important to students of speech. The brain is divided into two hemispheres, one of which (usually the left) is dominant in the processing of speech. Posteriorly, Wernicke's area is important for auditory comprehension. Broca's area, on the frontal lobe, is associated with the production of the motor movements involved in speech. Much of the coordination of all motor movements takes place in the brain stem and the cerebellum. You will locate these structures as well as the cranial nerves relevant to speech production in this dissection.

In order to observe these structures, you will have to cut through some of the meninges which cover the brain. The meninges are composed of three layers of connective tissue. In order from the outside, inward, the three successive layers of meninges are the (1) the dura mater, (2) the arachnoid, and (3) the pia. These layers will be discussed in more detail later.

Dissection

Prop the head of the cadaver up. Then, make an incision with a scalpel in the horizontal plane approximately 1 cm superior to the ears and eyebrows, completely encircling the skull, as shown in Figure 5.1. Reflect and remove the area of the skin thus delineated, removing as much of the osseous membrane as possible. This will help to keep the saw from slipping when cutting through the skull.

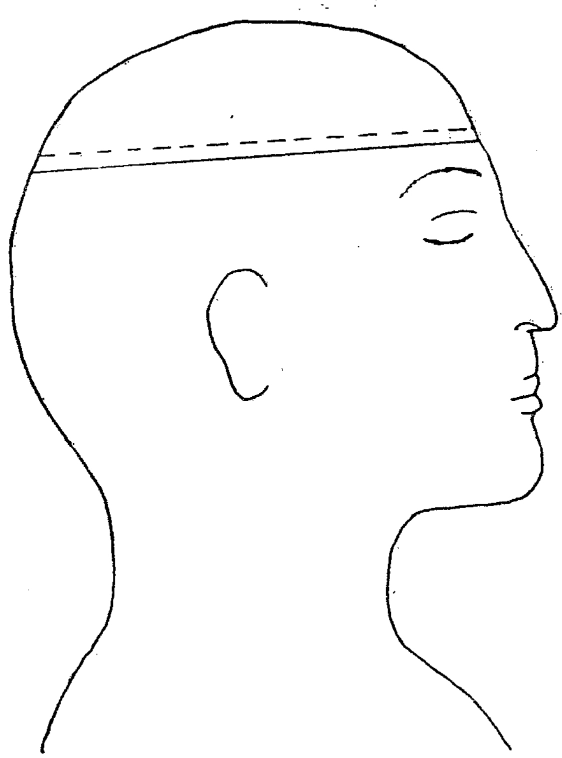

Figure 5.1. Removing the skull cap.

Mark the skull with a pen along a line just above that used for removing the skin. With an autopsy saw or a bone saw, cut along this line. Begin by cutting through the frontal bone laterally to the temporal bone. Then, turn the cadaver over, and cut from the temporal bone medially through the occipital bone.

Once you have made the circular cut in the skull, take a mallet and chisel and remove any last bits of bone tissue that may be left holding the skullcap on. Very carefully pry the skullcap free. The dura mater is a very tough and thick membrane adherent to the inner surface of the skull. When you lift the skullcap free, if you have not cut through the dura mater while making the incision, you will probably feel quite a bit of resistance. It may come off with the skullcap or may remain on the brain. After death, the brain may shrink, causing the arachnoid membrane to separate away from the dura mater. The arachnoid membrane covers the sub-arachnoid space, through which run many of the vessels supplying blood to the surface of the brain. The pia mater is deep to the sub-arachnoid space and separates it from the surface of the brain. The pia mater adheres closely to the entire surface of the brain, running into all its fissures.

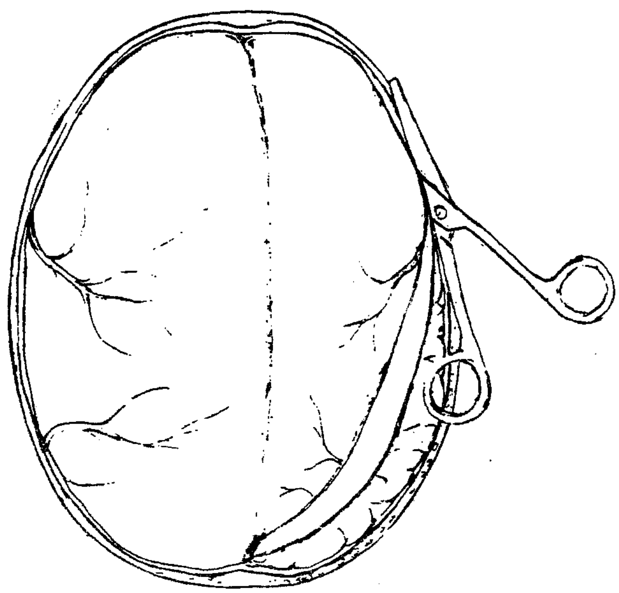

Figure 5.2. Incision and reflection of the dura mater.

If the dura mater has adhered to the brain, it must be removed. To remove the dura mater, puncture it with a scalpel. Take a pair of scissors and follow the sectioned edge of the skull cap. Make a complete circle around the opening of the skull (Figure 5.2). Gently lift up one side of the layer of the dura mater and observe the brain inside. At this time, you can observe the arachnoid covering the brain and may be able to see the fissured surface of the brain.

Once the cranial cavity has been opened, you should determine how well the brain has been fixed. When formalin is pumped into the cadaver, it does not necessarily penetrate all of the extremities. The brain is often insufficiently fixed. If this is the case, it will be quite soft. To fix an unfixed brain, remove it as described below and then keep it in a container of formalin.

If the brain is well fixed, you may have to remove some of the blood vessels which run along the fissures and sulci of the brain, in order to observe those structures. These vessels run through the sub-arachnoid space, a meningeal layer defined by the arachnoid membrane superficially, and the pia mater deeply. It should be noted that the pia mater is closely adherent to the entire surface of the brain, running into all the brain's fissures, whereas the arachnoid covers the whole brain without running into all the fissures.

Accordingly, removing the vascular net will necessitate removing all or part of the arachnoid membrane. If the brain is not fixed, the arachnoid and pia mater will be nearly transparent, and it is best to leave them intact. Note the complexity of the surface of the brain.

Next, locate the interhemispheric fissure, or longitudinal fissure, which separates the right and left hemispheres. When you find this fissure you should see an extension of the dura mater suspended in it. This tissue is called the falx cerebri ("falx" is Latin for "scythe"). Find the falx cerebri in the interhemispheric fissure.

Find the anteroinferior border of the falx cerebri and cut it with scissors or a scalpel blade. Reflect the severed falx cerebri as well as the rest of the incised dura mater posteriorly out of the way.

Next, remove a trapezoidal wedge of skin from the occiput (as indicated by dotted lines in Figure 5.3), starting one or two cm posterior to the ear and extending downward one or two cm past the base of the neck to a point about three cm lateral to the mid-line on both sides. Remove as much of the fatty and muscular tissue from this area as possible.

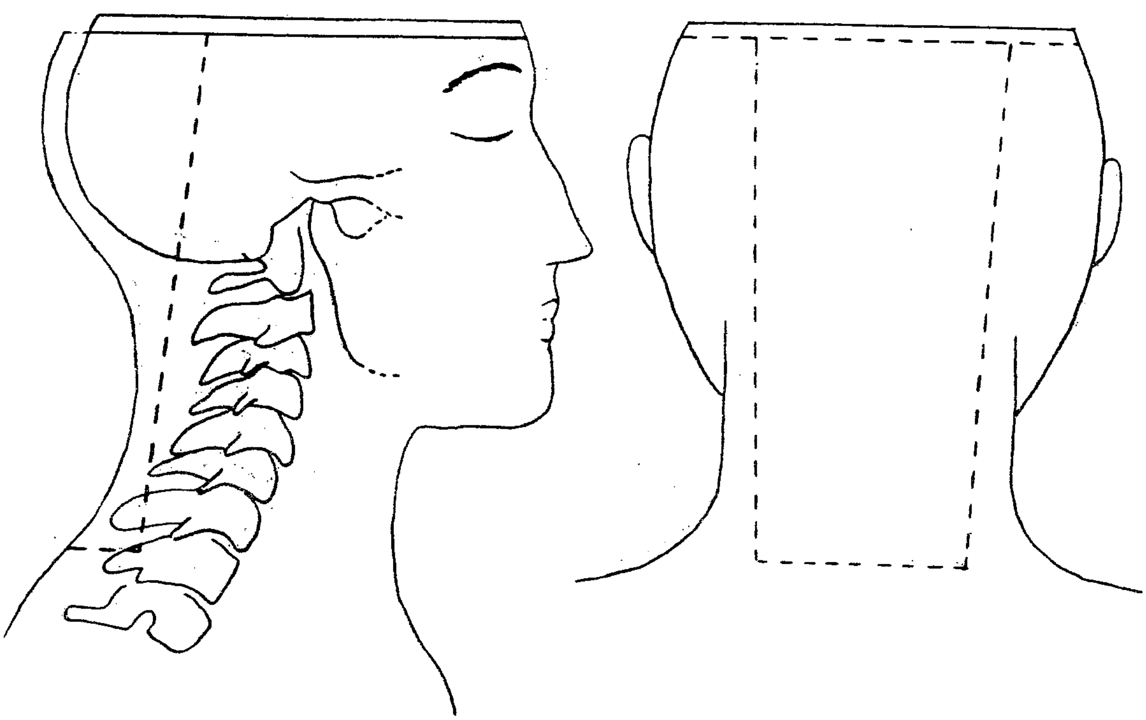

Figure 5.3. Trapezoidal excision to expose the posterior brain. Cuts through skin and muscle tissue indicated by dotted line. Lateral view (left) and posterior view (right). Silhouette of underlying bone shown on left for reference.

After exposing the underlying area of the skull, cut from the lip of the skullcap to the foramen magnum with an autopsy saw, avoiding slipping and taking care not to cut too deeply near the foramen, so as to avoid damaging the spinal cord (Figure 5.4). Again, by prying with a chisel, remove the wedge of occipital bone, detaching it from the dura mater underneath.

Observe the tentorium cerebelli, the fold of dura mater that projects horizontally between the occipital lobes of the cerebrum and the cerebellum. Cut the tentorium cerebelli at this time and remove it. As you remove it, observe the finely fissured lobes of the cerebellum underneath it.

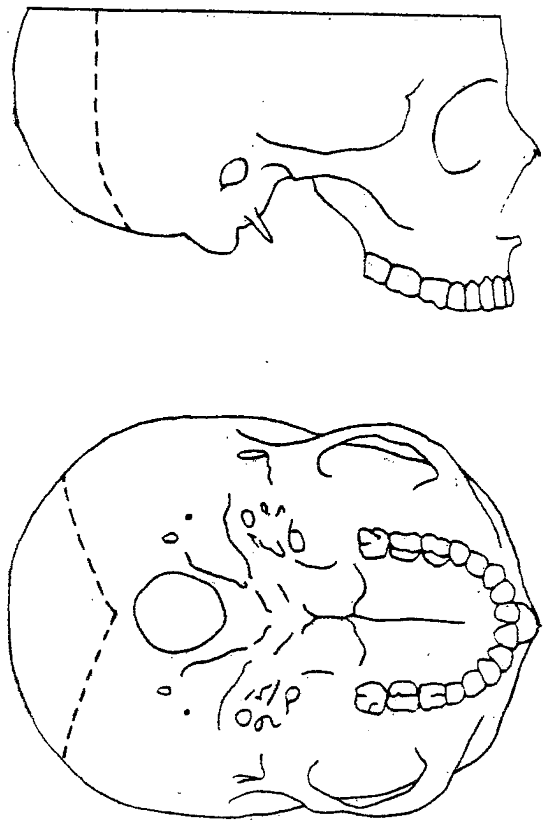

Figure 5.4. Schematic of cut into the occipital bone., Lateral view (top) and inferior view (bottom).

Between the two lobes of the cerebellum is one last dural reflection, the falx cerebelli. This should now be removed also. At this point you should have removed all the dural reflections of the brain. Both the falx cerebri and tentorium cerebelli should be removed. Look carefully at the brain as it sits in the cranial cavity and observe the lobes of the brain and how the cranial cavity envelopes it in a bony protective case.

Using the location of the removed piece of occipital bone, locate the cervical levels of the spinal cord in the foramen magnum. With a sharp scalpel blade, cut through the spinal cord at the lowest possible level down the neck. Once you have completely severed the spinal cord, make sure that you cut the arteries that surround the spinal column as well. At this time, change your orientation and locate the frontal lobes of the brain. Carefully and slowly, lift the frontal lobes up from the front. You will now be attempting to locate the various cranial nerves and will have to cut them, either with a sharp scissors or a scalpel blade, lifting the brain back as you do so. Remember, also that there are a lot of arteries around the base of the brain, and as you see these arteries, make sure you cut them. If you do not cut them, the brain will tear as you reflect it backwards. Take your time and gently pull the brain backwards, while cutting all the cranial nerves and arteries that are resisting your pull. Once you have done this, the entire brain should pull free.

Remove the brain and observe the cranial cavity. The cranial cavity is composed of three major fossae; (1) the anterior, (2) the middle, and (3) the posterior. The anterior cranial fossa supports the frontal lobe; the middle, the temporal lobe; and the posterior fossa, the cerebellum. Observe how these three lobes sit in the their respective cranial fossae.

At this time, focus your attention on the removed brain. Locate the lateral fissure and central sulcus.

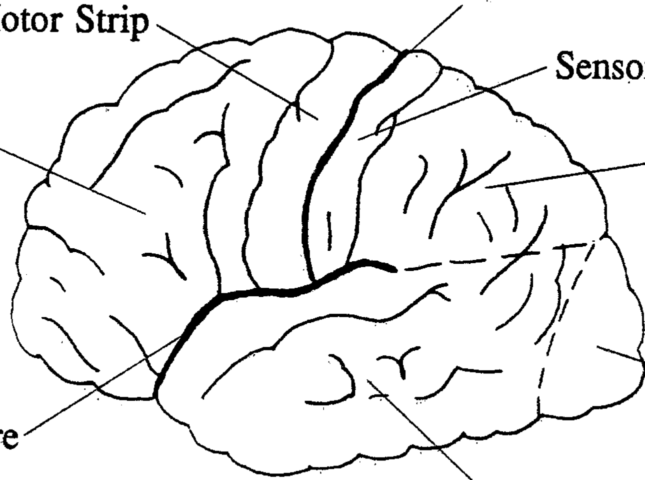

Figure 5.5. Left hemisphere of the brain (lateral view, anterior to the left of figure).

Make sure that you find the following landmarks on the brain before you begin to study it (Figure 5.5). First identify the frontal, parietal, temporal, and occipital lobes. Use the lateral fissure and the central sulcus to help pick out these particular lobes. Notice that the brain is bilateral, with both hemispheres separated by the longitudinal fissure. Gently separate the two hemispheres and look into the longitudinal fissure. As you look down you can see a large bundle of fibers which connect the two sides of the brain, the corpus callosum.

On the frontal lobe, just anterior to the central sulcus, on both hemispheres of the brain is a gyrus (a convex 'hill' defined by two sulci, or fissures) known as the motor strip. Just posterior to the central sulcus on the parietal lobe is an analogous gyrus called the sensory strip. Most of the motor control and sensory input for one side of the body is mediated by activity in the associated gyrus on the opposite side of the brain. The lower extremities are controlled by cortex on the superior portion of each strip, near the longitudinal fissure. The head and face are controlled by the inferior portion of each strip, near the lateral fissure.

Most of what we know about the function of individual portions of the brain comes from correlating brain damage with dysfunctions in the patient. Clearly, the skull provides strong protection to the brain. Thus any blow to the skull strong enough to damage the brain is likely to affect a wide portion of the brain, rather than a single, small area. Similarly, strokes and gunshot wounds generally affect wide areas of the brain. You should also remember that every brain, like every body, is different from all others.

For these reasons, sources disagree about the exact location of the major language centers of the left hemisphere (Figure 5.6). Most sources agree that Broca's area is on the inferior portion of the frontal lobe. In his famous paper, Paul Broca identifies a small section of the gyrus just anterior to the base of the motor strip (Brodmann's region 44). It should be noted however that even Broca's patient had damage to a wider portion of the brain than just this area. Most sources agree that the area defined by Broca and the inferior portion of the gyrus just anterior to that (Brodmann's region 45), are involved in language production.

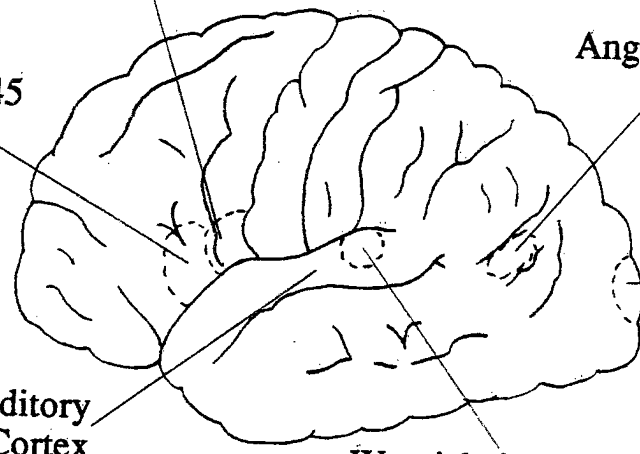

Figure 5.6. Major language centers of the brain.

Note the proximity of these areas to the base of the motor strip, which controls the head and face. Blows to this general area are likely to result in damage to the motor strip, resulting in motor aphasia, the acquired inability to speak. Broca's aphasia is often called motor aphasia, but it is generally understood that Broca's aphasia involves loss of some linguistic ability, resulting in a condition called agrammatism, and not simply motor paralysis of the speech organs. Many sources nevertheless include the base of the motor strip in Broca's area. Still other sources include regions of the frontal lobe superior and anterior to the regions discussed above.

Next locate the primary auditory cortex on both hemispheres of the brain. This is represented by the gyri making up the superior portion of the temporal lobe. Most auditory information is processed in this area.

On the left hemisphere, locate the approximate position of Wernicke's area. The precise location of this area also involves some controversy. Not only do authorities disagree, but the geography of the region itself varies considerably from brain to brain. Wernicke's area involves some region of auditory cortex in the posterior region of the temporal lobe. Thus, damage to Wernicke's area results in comprehension difficulties (as well as other kinds of disability) without disrupting the grammatical properties of speech. Generally, Wernicke's area is believed to control speech comprehension. It should be noted, however, that researchers have established that the region of Wernicke's area which is considered part of the auditory cortex is activated in deaf signers when they read sign language.

Locate the occipital lobe of both hemispheres. The occipital lobe and related structures are not as clearly delineated by anatomical landmarks as the other lobes and areas of the brain so such location is likely to be approximate. The primary visual cortex, where visual information is processed, is located on the posterior portion of the occipital lobe, at the very back of the brain. Between the primary visual cortex and the forward language centers in the left hemisphere, is a gyrus (or set of gyri) known as the 'angular gyrus'. Generally, it is an oblique gyrus, set at an angle with respect both to the gyri of the temporal lobe, which run mostly horizontally, and the gyri of the parietal lobe, which run mostly vertically.

The angular gyrus is known to be involved in reading, and damage to the angular gyrus can result in a condition called 'alexia' or 'acquired dyslexia', the inability to read written symbols.

Interestingly, alexia is usually accompanied by 'agraphia' or the inability to write, and only rarely occurs as 'pure alexia'.

Turning to the inferior portion of the brain, locate the cranial nerves on the brainstem. There are twelve cranial nerves which exit from the brainstem. The cranial nerves relevant to speech are the fifth (trigeminal), seventh (facial), eighth (vestibulocochlear), ninth (glossopharyngeal), tenth (vagus), and twelfth (hypoglossal). See the table at the end of this section. Find these cranial nerves on the brainstem.

Find the origin of the fifth (trigeminal) nerve on the lateral surface of the pons. In the skull, this large nerve (approximately 3 mm across) passes over the anterior surface of the petrous ridge and into a structure called Meckel's cave. Once you have located the trigeminal nerve on the brainstem, find the trigeminal nerve in the middle cranial fossa. Open up Meckel's cave and observe the trigeminal ganglion which is the location of the sensory cell bodies of the neurons of the trigeminal nerve. Find the three divisions of the trigeminal nerve (Figure 5.7). Most medially is the ophthalmic division, which exits the cranium through the superior orbital fissure. Lateral to it is the maxillary division, which provides sensory innervation to the area between the eyes and the mouth, and which leaves the cranium through the foramen rotundum. Most lateral is the mandibular division, which provides sensory innervation to the lower jaw and lower teeth, and anterior two-thirds of the tongue. It also provides motor innervation to the muscles which close the jaw, i.e. the temporalis, masseter and medial and lateral pterygoid muscles, as well as the anterior belly of the digastric and mylohyoid. It leaves the cranium through the foramen ovale.

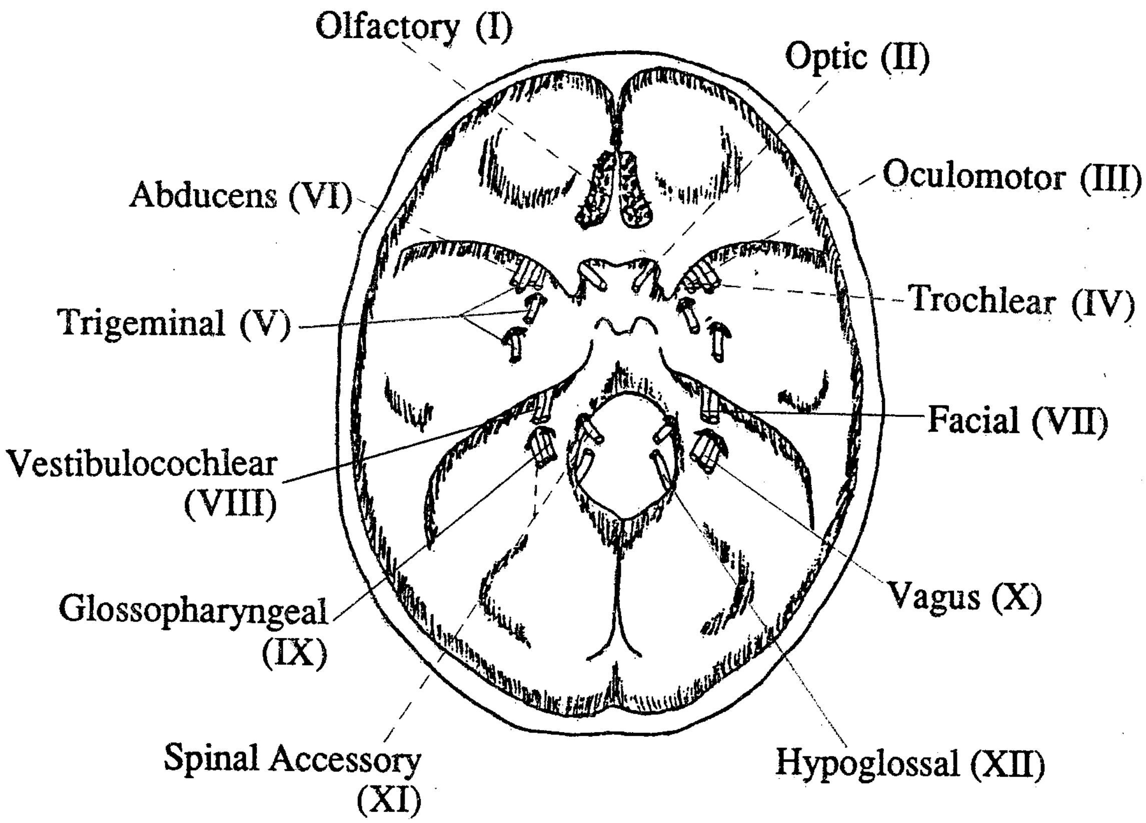

Figure 5.7. The cranial nerves and associated foramina, as seen within the skull cavity (brain removed and cranial nerves severed, superior view). Nerves not relevant to speech in indicated with dotted lines.

Next, on the removed brain find the seventh (facial) and eighth (vestibulocochlear) nerves, arising from the junction between the pons and the medulla of the brainstem. The seventh (facial) nerve provides motor innervation to the superficial muscles of the face, including depressor anguli oris, levator anguli oris, orbicularis oris, mentalis, levator labii superioris, depressor labii inferiorris, risorius, zygomaticus major, zygomaticus minor, and buccinator (see Figure 2.1). It exits the cranium via a foramen just medial to the styloid process, the stylomastoid foramen, on the interior surface of the cranium. The eighth nerve (vestibulocochlear) is the sensory nerve which innervates the vestibular and cochlear apparatus.

Now return to the cranial cavity (Figure 5.7) and locate the internal acoustic meatus on the back of the petrous ridge. Both the seventh and eighth nerve enter this foramen. The eighth nerve passes through this foramen reaching the cochlear and vestibular apparatus located deep inside the bone. The seventh cranial nerve enters this foramen and then emerges from the stylomastoid foramen to reach the muscles of facial expression.

Locate the ninth (glossopharyngeal) and tenth (vagus) cranial nerves on the medulla of the brainstem. The ninth nerve supplies general sensory innervation to the posterior third of the tongue, the mucous membrane of the pharynx, and areas of the soft palate. Keep in mind though, that a large portion of the general sensory innervation is supplied by the trigeminal nerve. The ninth nerve also supplies the motor innervation to the stylopharyngeus, one of the elevators of the pharynx. The tenth (vagus) nerve supplies sensory fibers to the pharynx and the larynx. It is also the major motor nerve which innervates all of the muscles of the larynx, both intrinsic and extrinsic. In addition, the vagus nerve innervates the elevators of the soft palate, levator palatini and tensor palatini, and the elevators of the pharynx, stylopharyngeus and palatopharyngeus. It also innervates the palatoglossus muscle, which helps to elevate the root of the tongue, and the constrictors of the pharynx and the larynx.

Once again, return to the cranial cavity and locate the jugular foramen, just below the internal acoustic meatus. Both cranial nerves nine and ten pass through this foramen to exit the skull.

Locate the twelfth cranial nerve (hypoglossal) on the brainstem. This nerve innervates all of the intrinsic and extrinsic (genioglossus, hyoglossus, styloglossus) muscles of the tongue. Now find the hypoglossal canal in the cranial cavity, the foramen through which the twelfth nerve fibers pass.

Table of Cranial Nerves and Their Functions

(nerves relevant to speech in bold)

#	Name	Function
I	Olfactory	Smell.
II	Optic	Vision.
III	Oculomotor	Motor to extraocular muscles (controls eye movements).
IV	Trochlear	Motor to extraocular muscles (controls eye movements).
V	**Trigeminal**	Sensory connections to face, soft and hard palate, nasopharynx, and anterior 2/3 of tongue. Motor connections to lateral and media pterygoid, temporalis, masseter, anterior belly of digastric, mylohyoid and tensor palatini.
VI	Abducens	Motor to extraocular muscles (controls eye movements).
VII	**Facial**	Sensory connections to taste from anterior 2/3 of tongue. Motor to muscles of facial expression, posterior belly of digastric and stylohyoid.
VIII	**Vestibulocochlear**	Hearing and balance.
IX	**Glossopharyngeal**	General sensory and taste sensation from posterior 1/3 of tongue. Motor to stylopharyngeus.
X	**Vagus**	General sensory from pharynx, larynx. Taste sensation from pharynx, larynx. Motor to cricothyroid, levator palatini, palatoglossus, palatopharyngeus, salpingopharyngeus, all intrinsic muscles of the larynx.
XI	Spinal accessory	Motor to sternocleidomastoid, trapezius.
XII	**Hypoglossal**	Motor to genioglossus, styloglossus, hyoglossus, intrinsic muscles of the tongue.

6. The Pharynx

Caution: In this dissection, you will cut through the spinal column. As always when dealing with CNS tissue, wear double gloves.

The principle object of this dissection is to observe the pharyngeal constrictors which form the back wall of the vocal tract. Begin by reviewing structures found in previous dissections. By palpation on the cadaver, locate the hyoid bone, the anterior aspect of the thyrohyoid membrane, the superior border of the thyroid cartilage and its superior cornu. Notice the thyroid notch in the midline. Below this, locate the cricothyroid muscle which connects the cricoid cartilage to the thyroid cartilage. Posteriorly, the recurrent laryngeal nerve can be seen adjacent to the joint of the cricoid and the thyroid cartilage.

Dissection

In order to achieve a posterior view of the pharynx, we will cut through the spine and the adjoining musculature. We will begin by isolating the structures we wish to preserve from those we will simply cut through by passing a probe through the retropharyngeal space. This is a region between two layers of fascia separating the spinal column from the esophagus and trachea. The pretracheal fascia encloses the organs in the anterior portion of the neck, and the prevertebral fascia encloses the spine and its musculature. Between these two fascia lies the retropharyngeal space.

Locate the retropharyngeal space and work a probe into it, separating the two layers of fascia (Figure 6.1). Enlarge the space by moving the probe up and down. Leaving the probe in place, turn the cadaver over to a prone position. Sever the attachments of the trapezius muscles to the cranium, the splenius capitis muscle and the levator scapulae muscle. Clear away all the muscles of the posterior part of the neck and all the sides. From the back you should see the cervical column of the skull. With a bone saw, cut transversely through the spinal column at a level anywhere between cervical vertebrae C1 and C4.

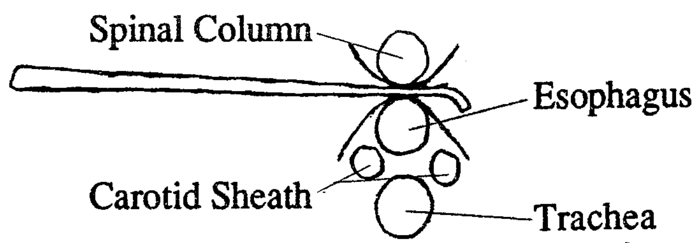

Figure 6.1. Schematic of a probe passed through the retropharyngeal space.

With a sharp scalpel, sever all the musculature of the prevertebral region up to the level of the probe in the retropharyngeal space taking care not to cut beyond this boundary. Turn the cadaver over and cut the trachea and esophagus as low as possible, at or below the level of the clavicle. The head is now severed from the body, and you can discard the lower portion of the cadaver at this stage.

Put the head upside down on the table with the cut skull resting flat, so that you are viewing the pharynx from the posterioinferior view. Because the head is now upside down, it is important to remember that all vertical directions in this section are given in relation to the cadaver in an upright position.

The pharynx is covered behind by the constrictor muscles. There are three constrictor muscles, the superior, the middle and the inferior.

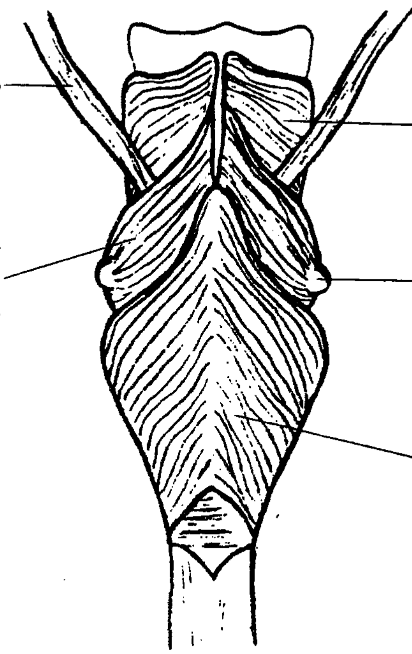

Figure 6.2. The pharynx from behind. Note also the posterior end of the greater horn of the hyoid bone in the medial pharyngeal constrictor.

The superior portion of the back of the pharynx—about level with the nose—is covered by the superior constrictor. The superior constrictor originates mainly from the posterior border of the pterygomandibular raphe. To observe this raphe, remove the medial pterygoid muscle which is attached to the medial pterygoid plate. These bones of the skull are not yet visible at this stage of the dissection. Notice how the constrictor muscles form the back wall of the pharynx and the buccinator forms the wall of the cheek; these two walls are contiguous and completely enclose the oro-pharyngeal cavity. Underneath the superior constrictor, the back wall of the pharynx consists of the pharyngobasilar fascia which is attached to the skull base. The upper edge of this fascia lies level with the hard palate.

The pharyngotympanic (eustachian) tube passes forward in the space between superior constrictor muscle and base of the skull. The stylopharyngeus muscle passes through the gap between the superior and middle pharyngeal constrictor muscles, on its way to the thyroid cartilage and the side wall of the pharynx. It is accompanied by the ninth (glossopharyngeal) nerve which gives it its motor innervation.

The middle constrictor muscle arises at the angle between the greater and lesser cornua of the hyoid bone, between the stylopharyngeus and the hyoid bone. Its fibers sweep back and attach to the median raphe, ranging vertically from overlapping fibers of the superior constrictor muscle superiorly to the level of the vocal folds inferiorly.

The middle and inferior constrictor muscles are divided by the thyrohyoid membrane which is attached between the thyroid cartilage and the hyoid bone.

Observe that the inferior constrictor muscle is composed of two distinct parts, the thyropharyngeus and the cricopharyngeus. The thyropharyngeus is attached anteriorly to the oblique line of the thyroid cartilage and from there sweeps posteriorly to the midline raphe. Superiorly, it is attached as high as the level of the soft palate. Inferiorly, its lowermost fibers are horizontal and adjacent to the cricopharyngeus. The cricopharyngeus is attached from one side of the cricoid arch to the other. There is thus no midline raphe. It is a sphincter at the lower end of the pharynx, which opens only during the act of swallowing.

Palpate for the superior cornu of the thyroid cartilage and the greater horn of the hyoid bone. With a sharp scalpel, make an incision between these two landmarks from left to right. From the midline of this first incision, cut the posterior wall of the pharynx, inferiorly to the upper end of the esophagus.

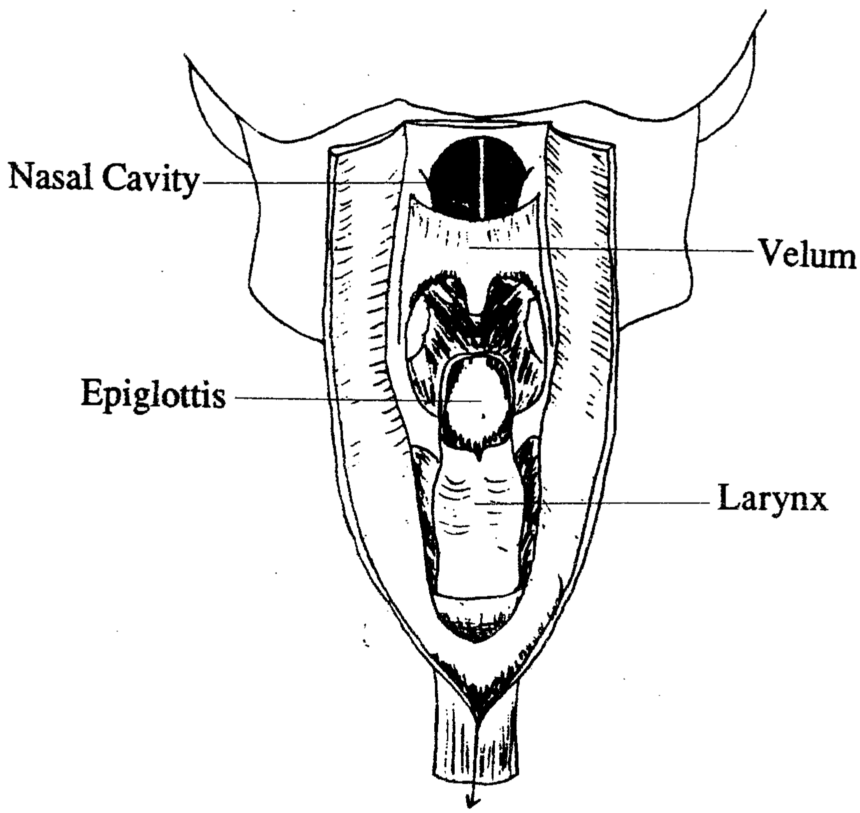

Figure 6.3. The pharynx from behind, opened. Note that the posterior musculature of the larynx is still covered with fascia.

Reflect the flaps of the pharyngeal wall thus formed laterally and study the structures of the interior of the pharynx and larynx (Figure 6.3). Shining a light down the tube of the larynx, one can see the vocal cords forming a V-shaped opening with the point of the V pointing anteriorly. Note that on the cadaver the vocal folds may be smaller than expected, and difficult to see.

The epiglottis, a leaf-shaped structure stands vertically attached by a stalk to the midline of the posterior aspect of the thyroid cartilage. The aryepiglottic folds run inferoposteriorly along the side of the epiglottis toward the arytenoid cartilage. The aryepiglottic muscles which lie beneath the mucosa covering these folds actually attach to the arytenoid cartilage.

Palpate for the corniculate cartilages at the bottom of the aryepiglottic folds. These structures are attached to the superior aspect of the arytenoid cartilages; these, in turn, sit on the sloping shoulders of the cricoid lamina, covered posteriorly by the fibers of the arytenoid muscle.

7. The Tongue

In this portion of the dissection we will concentrate on the muscles of the tongue. These are divided into extrinsic and intrinsic muscles. We shall first examine the attachments of the tongue's extrinsic muscles and attempt to understand how they serve to move and shape the tongue during speech. Then we shall bisect the tongue and excise one half. This will allow us to examine the tongue's intrinsic muscles and how they serve to move and shape the tongue during speech.

We will consider the four major external muscles of the tongue. The mylohyoid muscle is responsible for raising the body of the tongue in high vowels and velar consonants. The styloglossus pulls the tongue upwards and backwards. The hyoglossus pulls it downwards (and slightly backwards). The fourth major external muscle of the tongue, the genioglossus, forms the bulk of the inferior part of the tongue.

We have already observed the mylohyoid muscle in Section 4. The hyoglossus is a broad, flat muscle running from the greater horn of the hyoid to the posteroinferior lateral aspects of the tongue. The styloglossus extends from the styloid process, a projection of the skull at about the level of the ear, to the lateral aspect of the tongue superficially to the inserting fibers of the hyoglossus.

The genioglossus is attached to a point on the mandible about half way between the chin and the lower incisors. (Check by feeling with a forefinger down behind the lower front teeth in your own mouth, and noting where this muscle attaches.) From this point, the muscle fibers fan out posteriorly and superiorly to form the inferior portion of the tongue.

We will also observe the palatoglossus muscle, which is a small muscle that can assist the action of the styloglossus. The palatoglossus muscle can be found below the mucous membrane of the anterior faucal pillar on the posterolateral aspect of the tongue. From the undersurface of the soft palate, this muscle curves inferiorly to insert into the side of the tongue. The posterior faucal pillar is formed by the palatopharyngeus muscle, which does not effect the position of the tongue.

The intrinsic muscles which we will examine are: the superior longitudinal, the inferior longitudinal, the verticalis and the transversus. The superior longitudinal fibers run anteroposteriorly along the superior surface of the tongue, just below the mucous membrane. The inferior longitudinal fibers run along the sides of the tongue, from the root to the tip of the tongue. Anteriorly these fibers appear to join those of the styloglossus muscle. The verticalis fibers arise near the midline of the superior surface of the tongue and course inferolaterally to insert into the sides of the tongue. The transverse fibers extend from the mucous membrane on the sides of the tongue to the median septum which divides the tongue in half sagitally.

The actions of some of the muscles of the tongue are summarized in Figure 7.1.

Dissection

There are two possible approaches to the extrinsic tongue muscles. The first is to cut the right and left anterior bellies of the digastric as close as possible to the mandible. Reflect them up and back. Clean away all fat from the mylohyoid muscle and remove the rest of the submandibular gland. Note that the mylohyoid originates from the myloid (interior) ridge of the mandible on each side and meets at the midline raphe. This muscle also attaches to the anterior part of the hyoid bone. As we have noted, the mylohyoid forms the floor of the mouth and controls the raising of the tongue. It is also an elevator of the hyoid bone, hence it elevates the larynx. Find the posterior border of the mylohyoid muscle. Locate the origin of the hyoglossus near this point. Note how the hyoglossus is a depressor of the tongue. The hyoglossus inserts into the tongue from the hyoid bone. Section and reflect the hyoglossus, and you should now see the tongue.

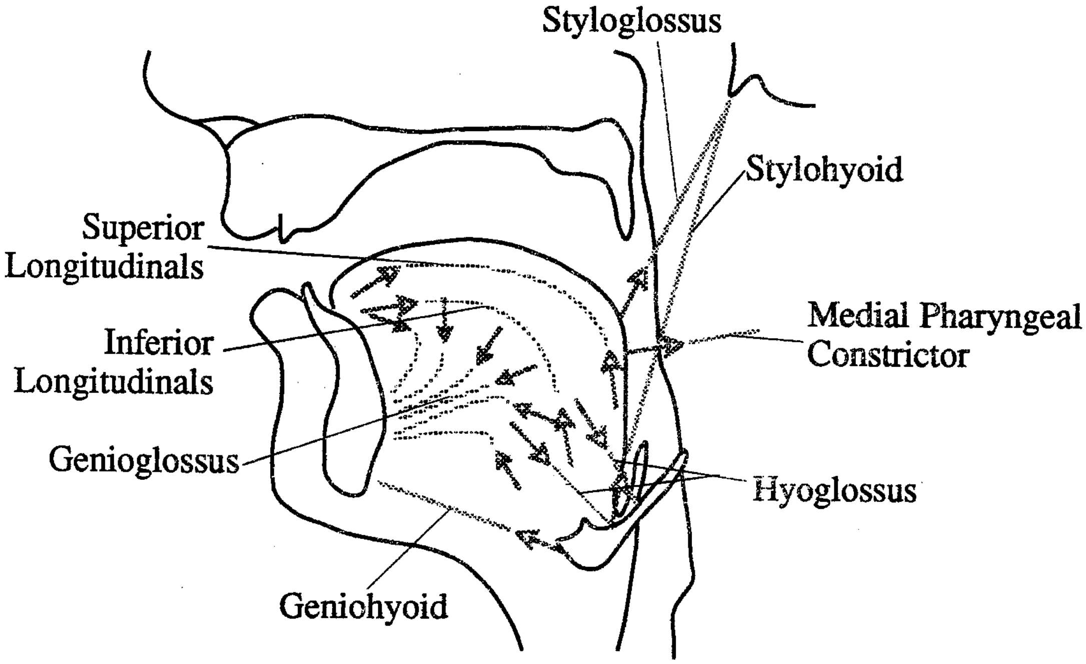

Figure 7.1. Schematic diagram of the action of some of the muscles of the tongue.

An alternative dissection begins by reexamining the superoanterior region of the pharynx. The general idea is to approach the styloid area from the medial side working laterally. To do this, locate the part of the stylopharyngeus muscle where it passes between the medial and superior constrictors and separate it from surrounding tissue. Clean up toward the styloid process. Look for the ninth (glossopharyngeal) nerve alongside or enclosed within the stylopharyngeus. Locate the lower end of the stylohyoid muscle where it wraps around the tendon of the digastric just above the hyoid bone. Follow the stylohyoid up to the styloid process. Locate the styloglossus muscle beneath the stylopharyngeus and stylohyoid. It should now be possible to observe the four muscles as a group (Figure 7.2.). These muscles are used to raise various structures by drawing them toward the skull. The digastric is attached to the skull at the mastoid process of the temporal bone. The other three muscles are attached to the skull at the styloid process. The posterior belly of the digastric raises the jaw. The stylopharyngeus raises the pharynx and the larynx. The stylohyoid raises the hyoid bone and thus the larynx. The styloglossus raises the tongue upward and backward and can also assist the intrinsic muscles in drawing the sides of the tongue upward.

Choose the side of the head in which the styloglossus is most easily observed as a result of previous dissection. Cut the mandible about one cm lateral to the mid-line on this side. If the posterior part of the mandible has not already been cut, make a further cut slightly anterior to its angle. Sever the mylohyoid close to the mandible, and reflect it medially and inferiorly. Remove the cut piece of the mandible. Leaving the mylohyoid attached to the hyoid bone, clean off the underlying muscles so as to be able to see the styloglossus and the hyoglossus. Some fibers of the styloglossus may form a raphe or interdigitate with the hyoglossus; other fibers may pass superficially over the hyoglossus and enter the tongue. Later it will be possible to observe further fibers passing deep to the hyoglossus before entering the tongue. At this time parts of the genioglossus and the geniohyoid may also be observed.

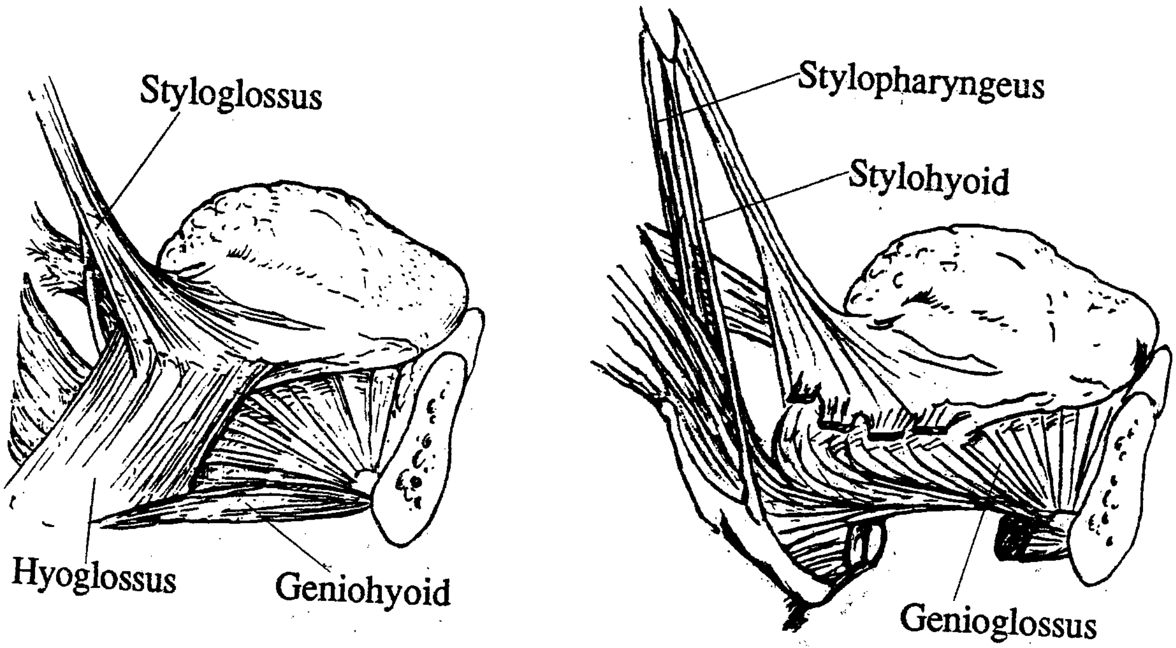

Figure 7.2. The extrinsic muscles of the tongue.

Detach the mylohyoid from the hyoid bone, so as to completely expose the geniohyoid. Detach the geniohyoid from the genioid process, and reflect it inferiorly. Using an inferior approach, observe the paired genioglossus muscles which arise from the superior genial tubercles, just superior or deep to the geniohyoid muscles.

Using a probe, separate the genioglossus and the geniohyoid, endeavoring to locate the course of the inferior fibers of the genioglossus. A small group of inferior and lateral fibers of this muscle attach to the hyoid bone. Medially, follow the larger part of the inferior surface of this muscle down, deep to the hyoid bone, and observe how they insert into the root of the epiglottis. To appreciate the relation of the genioglossus and the epiglottis, insert a probe along the inferior aspect of this muscle and then posteriorly (i.e. from within the pharynx) feel the tip of the probe in the neighborhood of the epiglottis.

With some care, it is possible to excavate the fatty and cartilaginous tissue inside the epiglottal sac from between the geniohyoid and the genioglossus, and determine that the posterior end of the genioglossus becomes the epiglottis. It is then possible to insert a probe anteriorly (i.e. from within the oral cavity) and feel the tip of the probe at the superior end of the epiglottis.

Detach the hyoglossus from the hyoid bone, and reflect it superiorly, revealing the parts of the styloglossus previously mentioned, which pass deep to the hyoglossus and enter the inferior part of the tongue. Also observe that a further group of the lateral fibers of the genioglossus pass lateral to the stylopharyngeus and insert into the medial pharyngeal constrictor.

Turn your attention now to the dorsum of the tongue and observe that its mucous membrane is thrown into papillae which give the tongue its velvety appearance. The anterior two-thirds of the dorsum of the tongue are demarcated from the posterior one-third by large, rounded papillae (the vallate papillae) which are arranged in the form of a V, with the apex pointing posteriorly to the foramen caecum. The latter is a remnant of the thyroglossal duct and a useful landmark. The undersurface of the tongue is smooth and the mucous membrane forms anteriorly a midline flange named the frenulum. Posteriorly along the dorsum, a midline flange named the glossoepiglottic fold runs between the posterior one-third of the tongue and anterior aspect of the epiglottis. From the sides of the latter structure, pharyngoepiglottic folds run laterally to the wall of the pharynx, more precisely to the greater cornua of the hyoid bone. These three folds enclose two shallow oval pits named valleculae behind the posterior one-third of the tongue.

Observe the palatoglossus muscle, found below the mucous membrane of the anterior pillar of the fauces on the posterolateral aspect of the tongue. From the undersurface of the soft palate, this muscle curves inferiorly to insert into the side of the tongue. The posterior pillar of the fauces is formed by the palatopharyngeus muscle.

With a sharp scalpel, bisect the tongue just lateral to the midline. Observe the fanning out of the genioglossus on the sectioned edge. Anteriorly, fibers can be seen running from close to the upper surface toward the lower surface of the tip of the tongue. In the region of the tip of the tongue there are fibers of the superior longitudinal muscles which run slightly below the surface of the tongue through its entire length. The muscle fibers fan out from posterior to anterior to attach to the mucous membrane of the tongue. The most inferior fibers attach to the body of the hyoid bone.

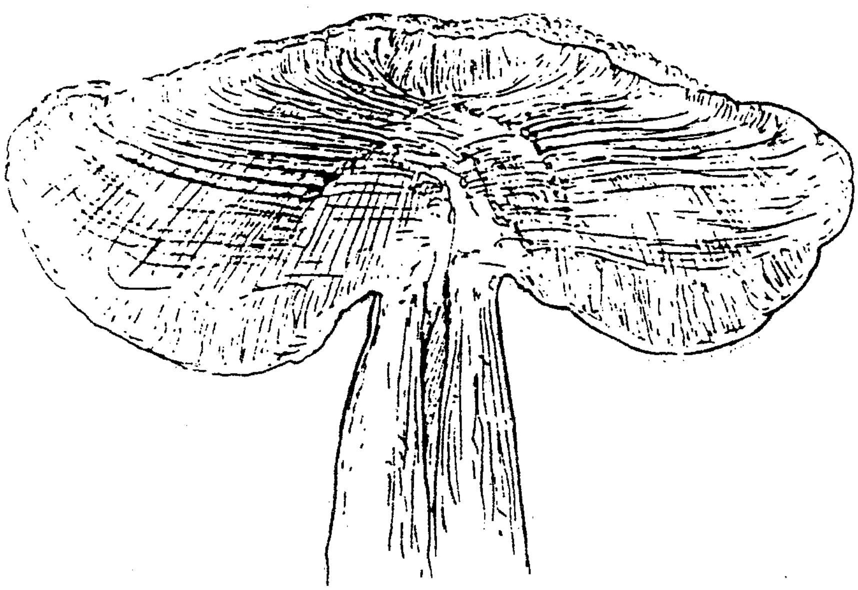

Figure 7.3. A coronal section of the tongue. Note complexity of intertwined muscle fibers.

Remove one half of the tongue from the mouth by cutting as close to the mandible as possible and close to the tongue posteriorly, being careful to leave as much of the soft palate intact as possible. Cut the excised half of the tongue coronally into successively posterior slices. Figure 7.3 exemplifies (for a whole tongue, rather than just one half) what such a section might look like. Cut the interior of the sections; attempt to observe the transversus fibers running from near the septum toward the sides of the tongue. Also observe the sublingual gland and its septum. With the half of the tongue that is still attached to the mouth, carefully remove the skin from the inferior portion of the tongue to expose the inferior longitudinal muscle. Observe the styloglossus and hyoglossus merging with the fibers of the inferior longitudinal muscles. Try to follow these fibers all the way to the apex of the tongue. Observe the boundary between the superior longitudinal muscle and the genioglossus at the midline of the tongue. Separate the muscles with a probe and then make an incision along this boundary. This should reveal many transversus fibers running out laterally from the lingual septum. Probe toward the upper surface of the tongue looking for further bands of superior longitudinal.

8. The Larynx

Adjustments of the larynx have multiple and interacting functions in speech, not all of which are well understood. The major movements that are relevant for speech production are the following.

(a) *Adducting/Abducting vocal cords.* The vocal cords can be fully adducted, for a glottal stop, or loosely adducted so that they vibrate for voiced sounds. The main muscles involved are the interarytenoids, which bring the posterior ends of the vocal cords together by moving the arytenoid cartilages together. In production of voiceless sounds the vocal cords are abducted by moving the vocal cords apart. This is principally achieved by using the lateral cricoarytenoid muscles to separate the arytenoid cartilages.

(b) *Lengthening/Shortening vocal cords.* The pitch of voiced sounds is largely controlled by varying the length of the vocal cords. As the cords are lengthened their mass per unit length is reduced, and consequently they vibrate faster. The cords are attached to the thyroid cartilage at the front and to the arytenoid cartilages, riding on the cricoid cartilage, at the rear, so their length is largely controlled by moving the thyroid and cricoid cartilages relative to each other. EMG studies suggest that lengthening the vocal cords is mainly achieved by using the cricothyroid muscles, but this is only part of the story. Since it is observed that the whole laryngeal structure tends to rise as pitch rises, external laryngeal muscles must also be strongly involved in pitch raising. It is unclear how much active shortening of the cords is possible; most likely pitch lowering is mainly achieved by relaxation of muscles used to reach a higher pitch.

(c) *Raising/Lowering of larynx.* Apart from the role the larynx raising plays in pitch control, the larynx is also raised or lowered to provide the initiation for glottalic sounds, such as ejectives (raising) and imposives (lowering), and to adjust the volume of the pharyngeal cavity. In this way the pharyngeal cavity is often enlarged for voiced obstruents and for advanced tongue root [+ATR] vowels and contracted for retracted tongue root [- ATR] vowels.

(d) *Tensing/Relaxing vocal cords.* Since the vocal cords consist in part of muscle (the vocalis portion of the thyroarytenoid muscle), they can also be inherently tensed and relaxed. It is probable that the degree of contraction of the vocalis fibers contributes to different modes of phonation.

Further comments on some of these functions will be made in the course of viewing and dissecting the intrinsic laryngeal structures described in this section.

Before dissecting the larynx, review the structures found in previous dissections in this region. Observe the thyroid cartilage (Figure 8.1). On the lateral border observe the cricothyroid muscle which arises from the arch of the cricoid cartilage and has two parts: one part inserts into the lower border of the thyroid cartilage, and the other is inserted obliquely into the anterior border of the inferior horn.

The cricothyroid joint allows for rotation around a transverse axis which runs between the inferior horns of the thyroid cartilage. Thus the front of the thyroid can draw either towards or away from the front of the cricoid. Contraction of the cricothyroid rotates the thyroid cartilage forward and relaxation allows other muscles to rotate it backward.

Because the vocal cords run from the front of the thyroid cartilage to slightly above the back of the cricoid, forward rotation lengthens and tenses the vocal cords while backward rotation shortens and relaxes them. Dickson and Maue-Dickson, whose discussion of this topic is clear and thorough, suggest that this action is sufficient to account for laryngeal changes in tension observed in the living larynx by cineradiography.

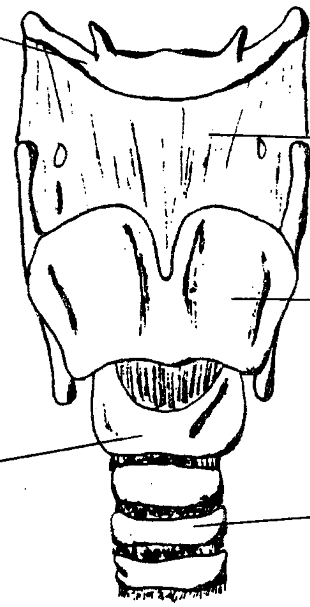

Figure 8.1. The laryngeal region, anterior view.

The next view of the laryngeal region will be a posterior one. Remove the mucous membrane which surrounds the posterior aspect of the larynx by using a pair of fine forceps and scissors. Lift the membrane away from the underlying structure and cut the fascia which anchors it to the muscles below. Ideally, the outcome should look something like figure 8.2.

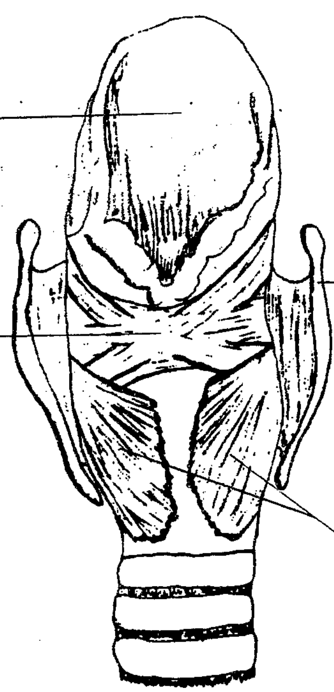

Figure 8.2. The external laryngeal muscles, posterior view.

Locate the posterior cricoarytenoid muscles which arise from the posterior aspect of the cricoid cartilage, lateral to the midline. This pair of muscles inserts into the laterally located muscular processes of the arytenoid cartilage. The muscle is fan shaped spreading out over the dorsal surface of the cricoid laminae on each side.

To understand the action of this muscle, the structure of the cricoarytenoid joint must be understood. This joint is saddle shaped. From the front, the ridges of the cricoid laminae run backwards, upwards and medially (posterosuperomedially). The cross-sections of the upper surfaces of the laminae are convex and rounded. To visualize the joint imagine a roof tile fitting over a cylinder. This type of joint affords two kinds of motion: the roof tile can slide along the cylinder's axis or it can slide around the cylinder - rotating about the cylinder's axis. One further constraint on the joint is the action of the posterior and lateral cricoarytenoid ligament. These two ligaments constrain the sliding motion which the arytenoid cartilage can make. According to Dickson and Maue-Dickson, only a few millimeters of slide is possible.

Contraction of the posterior cricoarytenoid muscle exerts a posteroinferior force on the muscular process of the arytenoid cartilage. This rotates the arytenoid posteriorly over the top of the cricoarytenoid joint. The two arytenoid cartilages thus rotate outward and away from one another. This abducts the vocal cords as in voiceless sounds.

Superior to the posterior cricoarytenoid, notice the oblique arytenoids. Each one of these muscles runs from the medial half of the muscular process of the arytenoid cartilage superomedially to the apex of the arytenoid cartilage on the other side of the larynx. On the way they cross one another and form an "X". Deep to the oblique arytenoids lies the transverse arytenoid; an unpaired muscle.

Contraction of both the oblique arytenoid muscles and the transverse arytenoid muscles—often referred to jointly as the interarytenoids—act to adduct the vocal folds. The oblique arytenoids draw the apex of each arytenoid toward the muscular process of the other. Because of the character of the cricoarytenoid joint, the arytenoid cartilages must rotate forwards to allow such an approximation. This rotation, in turn, adducts the vocal folds. Contraction of the transverse arytenoid muscle will have a similar effect.

To view the lateral and anterior aspect of the larynx, the thyroid cartilage must be dislocated. On one side of the larynx, locate the cricoid and thyroid cartilages. Dislocate the joint formed by the inferior cornu of the thyroid cartilage with the cricoid cartilage by prying the thyroid cartilage away from the cricoid cartilage with your finger. You should now be able to fold half of the thyroid cartilage forward and examine the lateral external aspect of the larynx.

Locate the lateral cricoarytenoid muscles which originate from the superior aspect of the cricoid lamina and run posterosuperiorly to attach to the muscular processes of the arytenoid cartilages. These muscles pull the arytenoid cartilages in an anteroinferolateral direction. This direction is along the axis of rotation for the arytenoid cartilage so these muscles are unlikely to cause any rotation. It is possible that they act to abduct the vocal cords slightly by exploiting the small amount of longitudinal motion allowed along the cricoarytenoid joint. Another possibility is that these muscles oppose the action of another muscle and prevent the joint from sliding longitudinally while allowing some rotation.

Now use a sharp scalpel to split the thyroid down the midline. Open the laryngeal cavity along the split to view the inside of the larynx. Inside the larynx, to one side, find the laryngeal ventrical, a longitudinal furrow between two folds in the laryngeal wall. The superior fold is the vestibular fold or false vocal cord. The true vocal cord is inferior and may be yellowish along the edge where the muscle gives way to ligament. Find the true vocal cords on the inside of the larynx and use this as a reference to find the thyroarytenoid muscle. This muscle lies beneath the vocal cords and attaches the posterior aspect of the thyroid notch to the anteriorly located vocal process of the arytenoid cartilages.

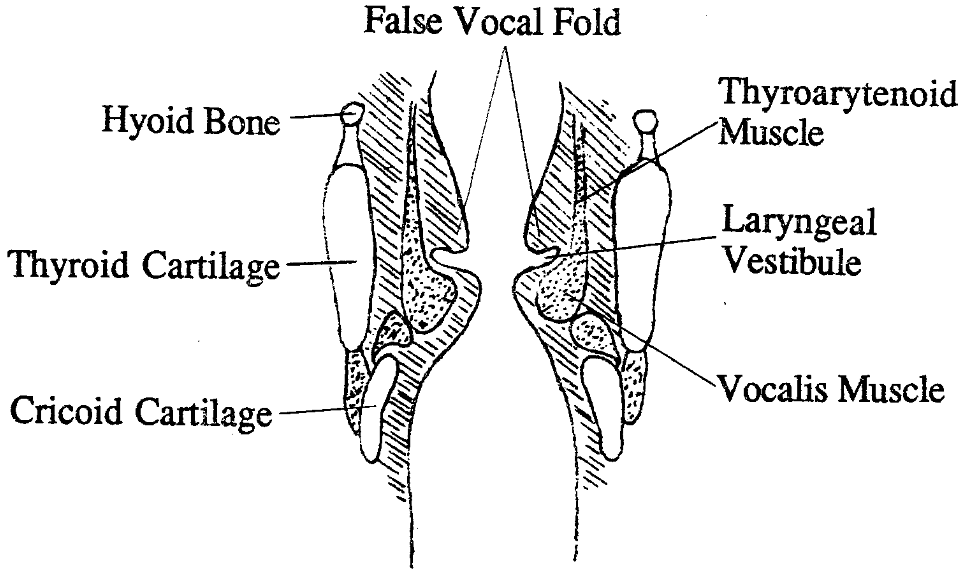

Figure 8.3. Coronal section through the larynx.

The thyroarytenoid has an antagonistic effect to that of the cricothyroid which tilts the thyroid forward and lengthens the vocal cords. The thyroarytenoid tilts the thyroid cartilage backward which results in a shortening of the vocal cords. It may be possible to manually tilt the thyroid and the cricoid back and forth with respect to one another and observe the effect on the vocal cords.

It is important to note that a subset of the muscle fibers of the thyroarytenoid muscle have been separately named the vocalis muscle (Figure 8.4). It is not practical to try to make this distinction between thyroarytenoid and vocalis muscle fibers. Just be aware that the muscle fibers of the thyroarytenoid muscle which directly underlie the true vocal fold are known as the vocalis muscle. Remove the mucosa from the true vocal cord, exposing the vocalis muscle beneath.

Cut the interarytenoids and the posterior cricoarytenoids away from the muscular process of the arytenoid cartilage on one side. This will allow you to observe the muscular process of the arytenoids and also rotate the arytenoids forward and backward on the cricoid cartilage, observing how this movement affects the vocal folds. Observe the vocal ligament and its attachment to the vocal process of the arytenoids and to the angle of the thyroid cartilage.

Detach any remaining muscular attachments to the partly dissected arytenoid cartilage and remove the cartilage from the larynx. Carefully remove all bits of muscle which may still be attached to it so you can see the shape of an arytenoid cartilage. Find the vocal process to which the thyroarytenoid and vocalis muscles attach and the muscular process to which the posterior and lateral cricoarytenoid muscles attach. Study the joint that the arytenoid cartilage makes with the cricoid cartilage. By inspection of the shape of the facets on the cricoid and arytenoid cartilage verify that the joint allows the kind of movements described above.

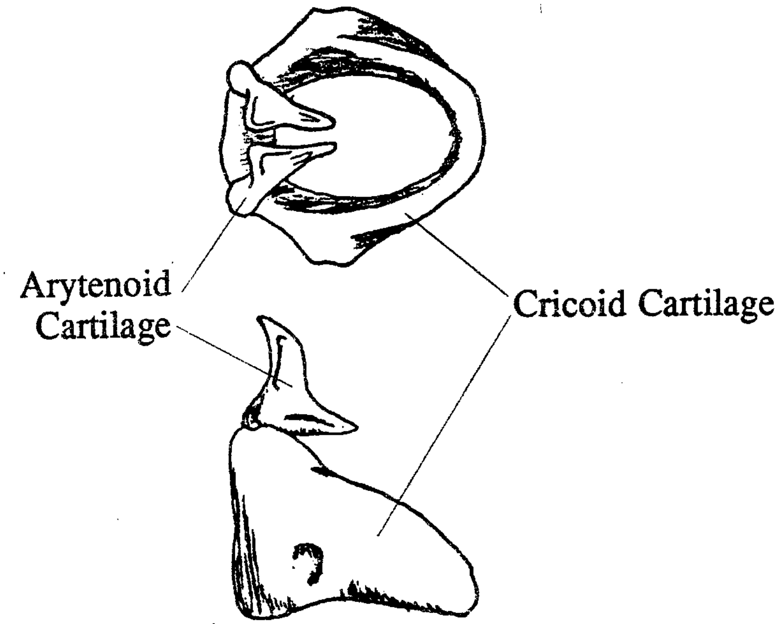

Figure 8.4. Articulation of the cricoid and arytenoid cartilages. Superior view (top) and lateral view (bottom); anterior to the right of figure.

Detach any remaining muscles from the hyoid bone, so that the thyrohyoid membrane can be observed (see figure 8.1). Note that this connection may result in an upward pull on the anterior portion of the thyroid cartilage when the hyoid bone is raised as the result of raising the tongue in the production of a high vowel. This will in turn lengthen the vocal cords and raise the pitch unless some compensatory action is taken.

9. The Velum

The palate is generally defined as the roof of the oral cavity and separates the nasal and oral cavities from one another. It is divided into a region with underlying bone called the hard palate and a region made up of connective tissue and muscle called the soft palate, or velum. (The terms 'soft palate' and 'velum' as used by linguists and phoneticians are largely interchangeable. We will continue to use the term 'soft palate', since anatomists and physiologists use the term 'velum' to refer to other physiological structures than just the soft palate.) The hard palate comprises about two thirds of the palate; the soft palate makes up the posterior third of the palate. Both regions are covered with mucosa. Because of the substances which comprise the two areas of the palate, the hard palate is fixed and immovable, while the soft palate is fleshy and moveable. This structure is an important one since, depending on the position of the soft palate, the oropharynx can be in open communication with the nasopharynx. This opening can be regulated because the soft palate can be tensed and elevated in order to seal off the nasopharynx from the oropharynx and oral cavity. For example, when food is swallowed, the soft palate raises so the food will pass down into the esophagus and not up into the nasal cavity. This action also controls the degree of nasality of sounds produced in speech.

Dissection

The dissection of the palate involves primarily the dissection of two muscles: levator palatini and tensor palatini. Both of these muscles insert into the soft palate and therefore can move it. The primary action of these muscles is to lift and tense the soft palate. Make sure to take careful notice of the origins and insertions of these two muscles and the path of their muscle fibers.

Bisect the skull sagitally using a bone saw and chisel as necessary.

Examine the nasal cavity and nasopharynx. Be sure to remove the nasal septum on the side of the head where it may still be intact. Keep in mind that you are viewing this area from medial to lateral on each side.

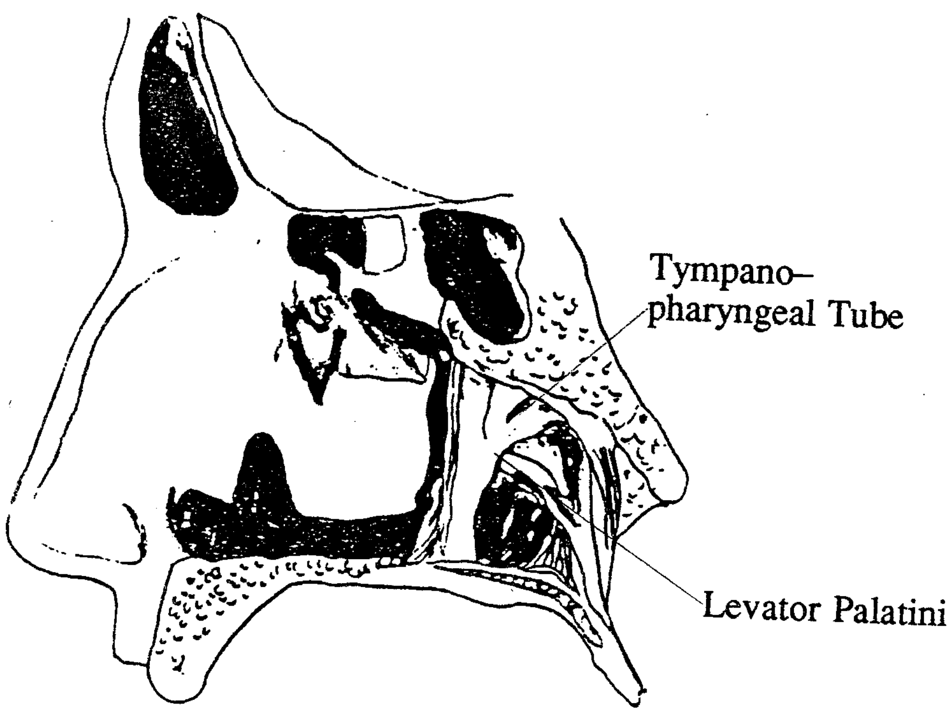

Figure 9.1. Mid-sagittal section of the head.

The lateral wall of the nasal cavity has three bony conchae attached to it, the superior, middle, and inferior. Observe the concha and then remove both the middle and inferior concha. You may either use sharp scissors or just break the concha off with a pair of forceps since the bone is very thin. Locate the opening of the tympanopharyngeal (eustachian) tube. This passageway serves to interconnect the middle ear cavity to the nasopharynx. The dissection will focus on the general area surrounding the eustachian tube.

With a scalpel very carefully remove the mucosa around the opening of the eustachian tube. Beneath the mucosa you should be able to find the levator palatini muscle. This muscle originates from the petrous bone and part of the eustachian tube and inserts into the soft palate. This muscle serves to elevate the soft palate to close off the nasal cavity from the oral cavity. It will be located immediately beneath the mucosa. Carefully study the course of the muscle fibers of the levator palatini. Notice how the muscle fibers seem to "flow and pour out of" the eustachian tube to insert into the soft palate. Study the action of this muscle by observing what would happen to the soft palate if the fibers contracted.

The next muscle to study is the tensor palatini. This muscle is located directly lateral to the medial pterygoid plate. Always remember that you are viewing the cadaver from medial to lateral. Therefore, you are viewing the medial pterygoid plate and not the lateral pterygoid plate. Remove the mucosa over the medial pterygoid plate. Locate the posterior border of the medial pterygoid plate and remove this mucosa also. At this time you may be able to see only a small portion of the muscle because the bulk of the muscle is hidden on the lateral side of the medial pterygoid plate. Take a small chisel, fracture the medial pterygoid plate (do not break the hamulus of the medial pterygoid plate) and remove the pieces. The tendinous fibers of the tensor palatini should now be seen.

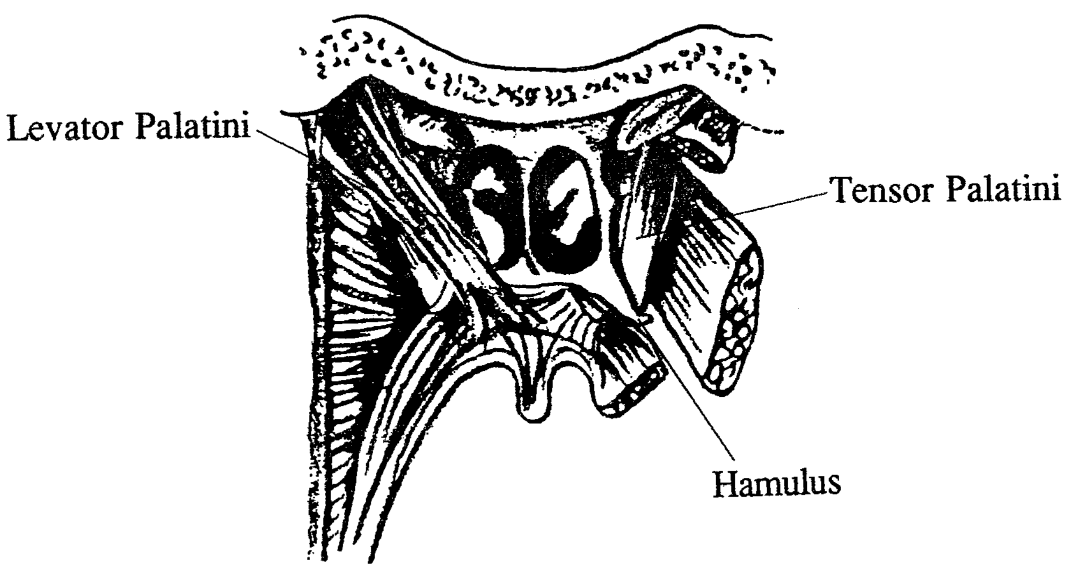

Figure 9.2. Posterior view of the nasal cavity. Levator palatini intact on left side, sectioned on right side to show tensor palatini, lateral.

Tensor palatini serves to tense the soft palate by pulling laterally on it. The fibers of this muscle originate from the scaphoid fossa between the medial and lateral pterygoid plates and pass around the hook of the hamulus of the medial pterygoid plate to insert into the soft palate. This muscle can be thought of as a ninety-degree muscle. It originates from the scaphoid fossa, passes vertically straight down and then loops around the hamulus at a ninety-degree angle to pass horizontally into the soft palate. Dissect the muscle fibers in as much detail as you can. Notice that the fibers of the tensor palatini which insert into the soft palate split into two separate groups of fibers. Some of them can tense the soft palate by pulling laterally, while the other group can also elevate the soft palate like the levator palatini does. This may serve to control very fine movements of the soft palate necessary for speech production mechanisms.

Appendix A: Glossary of Anatomical Terms

Not all the terms in this list appear in the dissector. However, they may be encountered in supplementary reading.

abduction	drawing away from midline
adduction	drawing toward the midline
adherent	sticking or clinging (< adhere)
alveolus	pouch in lung air sac
anterior	situated before or in front of (also ventral)
aorta	the large artery carrying oxygenated blood away from the heart
aponeurosis	expanded tendon for the attachment of a flat muscle
apposition	a fitting together
artery	vessel carrying blood away from the heart
articulation	connection between bones
autonomic nervous system	innervation of smooth muscle, heart muscle and glands
belly	central part of a muscle
body (of bone)	broadest or longest mass of bone
brachium	arm or branch
brainstem	base of the brain joining the spinal cord, includes the medulla oblongata, pons, and the midbrain
bronchus	one of two branches of the trachea entering the lungs
buccal	belonging to the cheek
cartilage	substance from which some bone ossifies; gristle
caudal	below; farther from the head (also inferior); used esp. for
central nervous system	the brain and spinal cord (abbreviated CNS)
cervical (vertebrae)	pertaining to the neck
clavicle	the collarbone; a long bone articulating the sternum medially and the scapula laterally
cornu	a small, horn-shaped projection of a bone (pl. cornua, adj. corniculate)
coronal	vertical; at right angles to sagittal (also frontal)
cortex	the outer portion of an organ, particularly the brain; gray matter
costal	pertaining to the ribs
cranial	upper; nearer to the head (also superior, rostral)
cranium	the skull; the portion of the skull containing the brain
deep	farther from the surface
depressor	that which lowers
dilator	that which regulates the opening of an aperture; a muscle that expands or enlarges an opening
distal	farther from a point of attachment
dorsal	toward the rear, back (also posterior); used esp. for the brain
eminence	a projection or prominence (of bone)
esophagus	muscular tube through which food is carried from the pharynx to the stomach
extension	straightening
fascia	a sheet of fibrous connective tissue that covers muscle
flexion	bending or angulation
foramen	hole, e.g. the *foramen magnum* is the hole in the skull through which the spinal cord connects to the brain stem (pl. foramina)
fossa	shallow depression (pl. fossae)
frontal	vertical; at right angles to sagittal (also coronal)

ganglion	group of nerve cells outside the CNS (pl. ganglia)
genioid (process)	pertaining to the chin (adj. genial; < Gk. gena 'chin'; see also *mental*)
gland	an organ or group of cells which secrete fluid
gyrus	a "hill" on the surface of the brain (pl. gyri)
head (of bone)	enlarged around end of a long bone; knob
in situ	in position
inferior	below; farther from the head (also caudal)\
innervate	to provide nerves (to muscles)
innervation	the distribution of nerves to an area
insertion	the area of attachment of a muscle to bone
interdigitate	to join finger-like branches
jugular notch	a "valley" or depression at the top of the sternum where the clavicles attach
jugular	pertaining to the neck
lamina	plate or layer (of bone)
lateral	farther from the midline
levator	that which raises
ligament	fibrous tissue binding bones together or holding tendons and muscles in place
lingual	belonging to the tongue
lumbar (vertebrae)	pertaining to the base of the torso; any of five vertebrae near the bottom of the spinal column
malar	belonging to the cheek
mandible	the jaw bone
manubrium	platelike bone forming the superior part of the sternum
margin	border
maxilla	the bone forming the upper jaw
meatus	an opening to the body
medial	nearer to midline
(osseus) membrane	a thin layer of tissue; the *osseous membrane* covers bone; the thyrohyoid membrane connects the thyroid cartilage and hyoid bone
midline	line dividing the body into left and right sides
mucosa	mucous membrane
neck (of bone)	constriction of bone near head
nerve	group of fibers outside the CNS
nucleus	group of nerve cell bodies inside the CNS
oblique	slanting
occiput	the back part of the head or skull
origin	fixed part of a muscle
palpate	to examine by touch
parietal	on the side or top; the *parietal pleura* is the pleural membrane facing the outside (cf. visceral)
pericardium	the membrane (actually an extension of the visceral pleura) covering and containing the heart (adj. pericardial)
pleura	the membrane(s) covering the lungs and inside of the thorax (cf. parietal, visceral; pl. pleurae)
plexus	a collection of nerve fibers
pons	structure of the brainstem connecting the medulla oblongata, midbrain and cerebrum
process (of bone)	projection
proximal	nearer to a point of attachment
pterygoid	wing-shaped; pertaining to the pterygoid bone, inferior to the sphenoid bone of the skull

pulmonary trunk	the region of the bronchus as it enters the lung
ramus	plate-like branch of bone; branch of a vessel or nerve
raphe	union of two parts (in a line)
reflect	pull or bend back
rostral	upper; nearer to the head (also cranial, superior)
sagittal	vertical plane or section dividing body into right and left
scapula	the shoulder blade
septum	a membrane or other structure separating two related structures (pl. septa)
serous	watery
sphincter	a circular band of muscle fibers that constrict an opening
sternum	the breastbone
subcutaneous	deep to the skin
sulcus	a "valley" on the surface of the brain (pl. sulci)
superficial	nearer to the surface
superior	upper; nearer to the head (also rostral, cranial)
tendon	fibrous tissue securing a muscle to its attachment (adj. tendinous)
tensor	that which draws tight
thoracic cavity	the inside of the rib cage; region of the heart and lungs
trachea	tube connecting the pharynx with the lungs
transverse	at right angles to long axis (also horizontal)
tubercle	small bump (can be felt with finger)
umbilicus	the navel
vascular	pertaining to the circulatory system, particularly arteries and veins
vein	vessel returning blood to the heart
viscera	soft organs of the body
visceral	pertaining to the viscera; the *visceral pleura* is the layer of the pleura that faces the lungs (cf. parietal)

Notes on terminology

1. Muscles are often identified by where they originate and where they terminate. For example, the sternohyoid muscle originates at the sternum and terminates at the hyoid bone.

2. The nerve roots that exit from the spinal cord are often abbreviated by the section of the spinal cord from which they emerge and their number (i.e.) how far down the cord they are at that particular level). For example, C1 is the first (most superior) nerve root which exits the cord at the cervical level (the most superior).

Appendix B: Muscles of the Speech Production Mechanism

I. MUSCLES OF RESPIRATION

A. MUSCLES OF INHALATION (muscles which enlarge the thoracic cavity)

1. Diaphragm

Attachments: The diaphragm originates in a number of places: the lower tip of the sternum; the first 3 or 4 lumbar vertebrae and the lower borders and inner surfaces of the cartilages of ribs 7 - 12. All fibers insert into a central tendon (aponeurosis of the diaphragm).

Function: Contraction of the diaphragm draws the central tendon down and forward, which enlarges the thoracic cavity vertically. It can also elevate to some extent the lower ribs. The diaphragm separates the thoracic and the abdominal cavities.

2. External Intercostals

Attachments: The external intercostals run from the lip on the lower border of each rib inferiorly and medially to the upper border of the rib immediately below.

Function: These muscles may have several functions. They serve to strengthen the thoracic wall so that it doesn't bulge between the ribs. They provide a checking action to counteract relaxation pressure. Because of the direction of attachment of their fibers, the external intercostals can raise the thoracic cage for inhalation.

3. Pectoralis Major

Attachments: This muscle attaches on the anterior surface of the medial half of the clavicle, the sternum and costal cartilages 1-6 or 7. All fibers come together and insert at the greater tubercle of the humerus.

Function: Pectoralis major is primarily an abductor of the arm. It can, however, serve as a supplemental (or compensatory) muscle of inhalation, raising the rib cage and sternum. (In other words, breathing by raising and lowering the arms!) It is mentioned here chiefly because it is encountered in the dissection.

4. Pectoralis Minor

Attachments: Deep to pectoralis major, this muscle attaches to the coracoid process of the scapula and the anterior ends of ribs 2 - 5.

Function: This muscle is also not primarily for respiration. Its main function is to lower the shoulder. If the pectoral girdle is fixed, it may, however, cooperate with pectoralis major in raising the upper ribs. It has been found to be active in forced inhalation.

5. Scalenes

Attachments: The anterior scalenes run from cervical vertebrae 3 - 6 to the upper surface of the first rib. The medials run from the lower 6 cervical vertebrae to just behind where the anterior inserts. The posterior scalenes run from the lowest 2 or 3 cervical vertebrae to the outer surface of the second rib.

Function: By contraction, the scalenes can raise the first two ribs, thereby expanding the thoracic cavity. They can thus assist the external intercostals in raising the ribs during inspiration.

B. MUSCLES OF EXHALATION (muscles which decrease the volume of the thoracic cavity)

1. Internal Intercostals

Attachments: The internal intercostals run from the anterior limits of the intercostal spaces to the angle of the ribs posteriorly. In front, they run inferiorly and laterally, and in back inferiorly and medially. Each muscle runs from the subcostal groove of one rib to the top of the rib immediately below it.

Function: The internal intercostals assist the external intercostals in strengthening the intercostal spaces. The internals are also the chief muscle in forced exhalation, for example during phonation. The internal intercostals - aided by the abdominal muscles - pull down the rib cage because of the direction of their fibers (opposite to the external intercostals). Note: as defined here, nerve fibers run within the internal intercostal muscles. Some researchers thus distinguish the 'internal' intercostal fibers which are superficial to this nerve, from the 'innermost' intercostals which are deep.

2. Internal Obliques

Attachments: The internal obliques originate in the lateral half of the inguinal ligament and the anterior half of the iliac crest. The fibers course almost vertically up to the lower borders of the cartilages of the last 3 or 4 ribs and the abdominal aponeurosis.

Function: The internal obliques assist other muscles in compressing the abdomen and thus raising the diaphragm and decreasing the vertical dimension of the thoracic cavity. They may also pull down on the lower three ribs.

3. External Obliques

Attachments: These muscles originate in the exterior surfaces and lower borders of ribs five to twelve. The fibers run in two directions: a) inferiorly and medially to the anterior half of iliac crest and near the midline of the abdominal aponeurosis and b) to the external layer of the abdominal aponeurosis.

Function: The external obliques compress the abdomen and draw the lower ribs downward. They may be used in forced exhalation.

4. Rectus Abdominis

Attachments: Rectus abdominis attaches at the crest of the pubis. The fibers run superiorly to the cartilage of the fifth, sixth and seventh ribs and the xiphoid process.

Function: This muscle is also used in forced exhalation. It can pull the ribs down and thus decrease the thoracic cavity and also push in on the abdomen forcing the diaphragm upwards thereby forcing air out of the lungs.

5. Subcostals

Attachments: These muscles have the same course as the internal intercostals, but are not confined to just one intercostal space. they are situated near the angles of the ribs.

Function: The function of these muscles is not known for sure. They may serve to depress the ribs.

6. Transversus Thoracic

Attachments: Transversus thoracic originates on the inner surface of the lower part of the sternum. The fibers run superiorly and laterally to the lower borders and inner surfaces of ribs two to six.

Function: These muscles may help to depress ribs for exhalation and may also tighten the intercostal spaces to help maintain the rigidity of the thoracic wall.

II. MUSCLES OF LIP MOVEMENT

A. MUSCLES WHICH CLOSE THE LIPS

1. Orbicularis Oris

Attachments: Orbicularis Oris is the sphincter muscle of the mouth, many of the other facial muscles blend in with it. Its fibers run in several directions. The intrinsic fibers (very thin layer) extend from the incisive slips under the nose to the mental slips at the midline under the lower lip. The extrinsic fibers arise from the buccinator through the modiolus. The uppermost and lowermost fibers go directly across the upper and lower lips to the other side. The middle fibers cross each other, the upper ones going below the lower lip and the lower ones going above upper lip.

Function: On contraction, this muscle adducts the lips by drawing the lower lip up and the upper lip down, probably in conjunction with some of the other facial muscles. It may also pull the lips against the teeth. This muscle can also round the lips by its sphincter action.

B. MUSCLES WHICH RAISE THE UPPER LIP

1. Levator Labii Superioris

Attachments: This muscle originates on the inferior orbital margin and parts of the zygomatic bone. The fibers course inferiorly and insert in the upper lip.

Function: As its name indicates, levator labii superioris raises the upper lip. It may be useful to raise the upper lip in the production of labiodental fricatives, particularly in languages such as Ewe that have contrasting bilabial fricatives.

2. Levator Labii Superioris Alaeque Nasi

Attachments: This muscle originates on the frontal process of maxilla The fibers run inferiorly and laterally along the sides of the nose and divide into two slips. One slip inserts in the alar cartilage (around nostril) and the other continues down to the upper lip.

Function: The muscle elevates the alar cartilages (dilates nostrils) and also elevates the middle part of the upper lip.

3. Zygomaticus Minor

Attachments: Zygomaticus minor originates on the facial surface of zygomatic bone. Running inferiorly and medially, the fibers insert into the modiolus and orbicularis oris, just lateral to the midline.

Function: Raises upper lip for [f] along with the muscles which raise the angles of the mouth.

C. MUSCLES WHICH LOWER THE BOTTOM LIP

1. Depressor Labii Inferioris

Attachments: Depressor labii attaches on the oblique line of mandible near mental foramen. Fibers run superiorly and medially to orbicularis oris and the skin of the lower lip.

Function: Draws lower lip downward and laterally, useful in the release of bilabial consonants.

D. MUSCLE FOR ROUNDING OF LIPS

1. Orbicularis Oris (see under muscles which close the lips)

E. MUSCLES WHICH PROTRUDE THE LIPS

1. Mentalis

Attachments: Mentalis originates on the mandible near mental tuberosity (side of chin). Fibers course superiorly, some reaching orbicularis oris, others inserting at different places along the way.

Function: On contraction, mentalis draws the skin on the chin upwards, at the same time everting and protruding the lower lip. In conjunction with orbicularis oris it helps round and protrude the lips for the high rounded vowels [u] and [y]. It also may help to close lips.

2. Orbicularis Oris--deep fibers (see under muscles which close the lips)

F. MUSCLES WHICH RETRACT THE ANGLES OF THE MOUTH

1. Buccinator

Attachments: Buccinator attaches to the pterygomandibular raphe and lateral surfaces of the mandible and the maxilla opposite the molar teeth. The fibers course medially and insert in the modiolus, with some continuing on into the upper and lower lips, forming the more superficial fibers of orbicularis oris.

Function: The buccinator draws the lips back against the teeth and pulls the angles of the mouth laterally as an antagonist to the muscles of protrusion and rounding. This action is probably utilized in the production of labiodental and bilabial fricatives. If the lips are actively spread in pronunciation of vowels such as [i] and [e] (which seldom happens), this muscle may be used.

2. Risorius

Attachments: The risorius is sometimes regarded as an extension of the platysma. The fibers have their origin at the fascia of the masseter near the ramus of the mandible. The fibers run horizontally, parallel and superficial to the buccinator, inserting in the modiolus, some continuing on to the upper and lower lips.

Function: The risorius draws the mouth angles laterally to help spread the lips in the production of [i], and [e] (although note the comment in the discussion of buccinator.). It may also aid the buccinator and zygomaticus major in pulling back the angles of the mouth during labiodental and bilabial fricatives.

3. Zygomaticus Major

Attachments: Zygomaticus major attaches on the outer edge of zygomatic bone, just lateral to zygomaticus minor. In some cases it inserts into the more superficial connective tissue which extends to cover the temporalis muscle. The fibers course inferiorly and medially to insert into the modiolus and orbicularis oris of the upper lip.

Function: On contraction, this muscle draws the angle of the mouth upward and laterally. the upward movement probably works with levator anguli oris to achieve the raised upper lip in labiodental fricatives. The lateral movement may be used in the production of [s].

G. MUSCLES WHICH RAISE THE CORNERS OF THE MOUTH

1. Levator Anguli Oris

Attachments: Levator anguli oris runs from the canine fossa on the maxilla coursing inferiorly and slightly laterally; most fibers insert in the modiolus with a few continuing on to insert in the lower lip.

Function: This muscle draws the corner of the mouth upwards and, because of the fibers which insert into the lower lip, may assist in closing the mouth by drawing the lower lip up, for the closure phase in bilabial consonants.

2. Zygomaticus Major (see under muscles which retract the angles of the mouth)

H. MUSCLES WHICH LOWER THE ANGLES OF THE MOUTH

1. Depressor Anguli Oris

Attachments: Depressor anguli oris attaches to the oblique line of mandible. This muscle is superficial and lateral to depressor labii inferioris. It runs vertically upwards, interdigitating with the platysma, and inserts into the modiolus. Some fibers continue up to the upper lip.

Function: To depress the angles of the lips, which may work with depressor labii inferioris to prevent the mouth from closing entirely when spreading for vowels like [i] and [e]. Because of the fibers which insert in the upper lip, this muscle may also aid in compressing lips by drawing the upper lip down.

2. Platysma

Attachments: Platysma originates in the fascia covering superior parts of pectoralis major and deltoid muscles. Fibers course superiorly and anteriorly, some inserting into the lower border of the mandible, blending with depressor labii inferioris and depressor anguli oris, some turn more medially and met the corresponding fibers from the other side on the chin, some go up into the modiolus, and some even continue up to the zygomatic arch and orbicularis occuli.

Function: The platysma can aid depressor anguli oris and depressor labii inferioris to draw down and laterally the angles of the mouth.

III. MUSCLES OF MANDIBULAR MOVEMENT

A. MUSCLES WHICH RAISE THE MANDIBLE

1. Masseter

Attachments: The masseter has its origin at the zygomatic arch. It inserts in the ramus of the mandible.

Function: This muscle closes the jaws by elevating and drawing forwards the angle of the mandible.

2. Medial Pterygoid

Attachments: The medial pterygoid originates in the pterygoid fossa and the medial surface of the lateral pterygoid plate. The fibers run inferiorly, laterally and posteriorly to the medial surface of the ramus and angle of the mandible.

Function: The medial pterygoid works with the masseter and temporalis to raise and protrude the mandible. It serves also as an antagonist to the anterior suprahyoid muscles to balance the lip position for labiodental fricatives and adjust the jaw position for [s].

3. Temporalis

Attachments: The temporalis originates from the entire temporal fossa. The fibers pass under the zygomatic arch to the anterior border of the ramus of the mandible.

Function: The function of this muscle is to raise the mandible (along with the masseter and the medial pterygoid). The posterior fibers retract the mandible slightly, assisted by the anterior suprahyoid muscles.

B. MUSCLES WHICH LOWER THE MANDIBLE

1. Anterior Belly of the Digastric

Attachments: This muscle runs from the inside surface of the lower border of the mandible. The fibers course inferiorly and posteriorly to the intermediate tendon near the lesser cornu of the hyoid bone.

Function: The function of this muscle is to draw the hyoid bone up and forward. It also serves to bring the tongue forward and upward for alveolar and high front vowel articulations. In pulling up the hyoid bone, it may also pull up the larynx thereby tensing the stretching the vocal cords and raising the pitch. If the hyoid bone is fixed, the anterior belly of the digastric can serve to lower the jaw in conjunction with the geniohyoid, mylohyoid and lateral pterygoid muscles.

2. Genioglossus (see under Muscles of the tongue)

3. Geniohyoid

Attachments: Geniohyoid attaches on the anterior inner surface of the mandible at the mandibular symphasis. Fibers run posteriorly and inferiorly to the anterior surface of the body of the hyoid bone. It is close to the midline of the floor of the mouth.

Function: When the mandible is fixed, the geniohyoid (along with the lateral pterygoid, the anterior belly of the digastric and the mylohyoid) pulls the hyoid bone upward and forward. This will raise both tongue and larynx. The geniohyoid may also serve as an antagonist to the thyrohyoid, tilting the hyoid and with it the thyroid cartilage backward, for velar and uvular articulations. If the hyoid bone is fixed by other muscles, the geniohyoid can become an active jaw opener.

4. Mylohyoid

Attachments: The mylohyoid muscle originates from the mylohyoid line along the inner surface of the mandible. Coursing medially and inferiorly, the fibers join those of the opposite side at the raphe and down to the corpus of the hyoid bone.

Function: When the mandible is fixed, the mylohyoid helps to elevate the hyoid and bring it forward and with it the floor of the mouth and the tongue. With the hyoid bone fixed, the mylohyoid may depress the mandible. It helps bring the tongue forward for alveolar articulations and, along with the posterior belly of the digastric, the stylohyoid and the medial pharyngeal constrictor, helps bulge the tongue up and back for velars. It is also active in high vowels whether front or back, in that it raises the whole body of the tongue.

5. Lateral Pterygoid

Attachments: This muscle attaches to the lateral portion of the greater wing of the sphenoid bone and the lateral surface of the lateral pterygoid plate. Running horizontally and posteriorly, the fibers insert in the pterygoid fossa and the temporo-mandibular joint.

Function: The lateral pterygoid muscle protrudes the mandible, causing the condyle to slide down and forward. This protrusion is useful in the articulation of [s] and [ʃ] and, for some people, [f]. It can also depress the mandible along with the other depressors discussed above.

IV. Muscles of the Tongue

A. Intrinsic muscles which change the shape of the tongue

1. Superior Longitudinal

Attachments: These muscles attach to the median fibrous septum and mucous membrane at the root of the tongue (close to the hyoid bone). Some fibers go back to the epiglottal ligament. The fibers course anteriorly along the length of the tongue very superficially and insert in the mucous membrane at the tip of the tongue. Laterally, the fibers join with the longitudinal fibers of the styloglossus, hyoglossus and inferior longitudinal muscles.

Function: On contraction, this muscle shortens the tongue, perhaps widening it at the same time. It can also bulge the tongue upwards as it shortens it, probably with the help of the inferior longitudinal to pull the tip of the tongue downwards. Since the fibers are inserted in the tip, this muscle can probably also raise the tip of the tongue for tongue tip dental and alveolars and retract it a bit for retroflex articulations. The lateral fibers may (along with styloglossus and perhaps palatoglossus) help keep the sides of the tongue raised during grooved articulations such as [s] and [z].

2. Inferior Longitudinal

Attachments: These muscles attach to the hyoid bone and root of tongue. Fibers course anteriorly lateral to the midline on the inferior side of the tongue between the genioglossus and hyoglossus muscles and insert into the inferior part of the tongue tip, blending with the fibers of the genioglossus, hyoglossus and styloglossus.

Function: This muscle pulls down and retracts the tip of the tongue for the release of tongue tip stop consonants. It acts as an antagonist to superior longitudinal and styloglossus for delicate control of tongue configuration as in grooving for [s]. By depressing the tip and bulging the tongue upwards, it helps from the articulations of back vowels and velar consonants.

3. Transverse

Attachments: These muscle fibers attach at the median fibrous septum and, near the tip of the tongue, from fibers of same muscle on the other side. The fibers course laterally to the lateral margins of the tongue, inferior to the superior longitudinal and superior to the inferior longitudinal. They insert into the submucous fibrous tissue in a fan-like distribution. Near the tip the fibers interdigitate with fibers of the superior longitudinal, inferior longitudinal and perhaps those of styloglossus and hyoglossus.

Function: On contraction, these fibers narrow and elongate the tongue. They draw the edges of the tongue upwards, aiding in grooving the tongue. They may also aid genioglossus in pushing the tongue forwards for front articulations when the tongue is coming from a back position.

4. Vertical

Attachments: These muscle fibers attach to the mucous membrane of dorsum of tongue. The fibers course inferiorly and vertically on either side of the median fibrous septum, inserting in the mucous membrane on the ventral side of the tongue. Some fibers interdigitate with fibers from the transverse and inferior longitudinal muscles.

Function: On contraction, the vertical fibers flatten the tongue and push the tongue out laterally to make contact with the roof of the mouth in palatal and alveolar stops. This tongue position may also be used in high front vowels. It is also used in making a seal between the upper and lower teeth during the production of [s]. The median fibers may act independently to flatten the middle of the tongue for grooved articulations.

B. EXTRINSIC MUSCLES (muscles which change the position of the tongue in the mouth as well as shape the tongue to some extent)

1. Genioglossus

Attachments: Genioglossus runs from the superior mental spina on posterior surface of the mandibular symphasis. The lower most fibers course posteriorly back to the anterior surface of the hyoid bone. Other fibers curve and fan out anteriorly and superiorly to insert into the submucous fibrous tissue near the midline from the root of the tongue to the tip. Some fibers may interdigitate with those of the superior pharyngeal constrictor.

Function: Contraction of posterior fibers protrudes the tongue when the mandible is fixed. This is useful in the production of nearly all sounds articulated in the front of the mouth. The anterior fibers retract the tongue on contraction and also depress the tip somewhat, and are probably used in the release of alveolar stop consonants. Besides its function as a muscle of the tongue, the genioglossus can also help to elevate the hyoid bone (and thus the larynx) when the mandible is fixed.

2. Hyoglossus

Attachments: This muscle attaches to the greater horn and body of hyoid bone. The anterior fibers attach to the mucous membrane at the tip of the tongue. The posterior and medial fibers interdigitate with the styloglossus and the inferior longitudinal muscles at the lateral edges of the tongue. One small bundle coming from the lesser cornu of the hyoid bone parallels the hyoglossus and inserts in the intrinsic muscles on the side of the tongue and the tip. This is sometimes considered a separate muscle: the chondroglossus (chondro = cartilage).

Function: When the hyoid is fixed, the hyoglossus can lower the tongue. The anterior fibers join with the genioglossus and inferior longitudinal muscles to retract the lower tongue tip. The posterior fibers (which insert on the lateral edges of the tongue) tend to pull down the sides of the tongue on contraction, thus serving as antagonists to styloglossus and palatoglossus (when the soft palate is fixed and contribute to the delicate adjustment of grooved fricatives. It may also work with styloglossus in the production of back vowels (tongue bunching with sides down) and the anterior fibers may balance the forward action of the posterior genioglossus fibers to position the tongue precisely in front vowels.

3. Palatoglossus

Attachments: This muscle attaches to the undersurface of the soft palate, interdigitating with the opposing fibers from the other side. The fibers continue inferiorly and laterally, forming the anterior pillars of the fauces and then insert at the edges of the tongue, interdigitating with the transverse, styloglossus and hyoglossus muscles.

Function: With the soft palate fixed, the palatoglossus muscle can assist styloglossus in raising the back of the tongue. In this it serves as an antagonist to the hyoglossus. It also aids the styloglossus and inferior longitudinal muscles to bulge the back of the tongue for velars. Because it inserts in the sides of the tongue and comes from a superior origin, it may also serve to groove the back of the tongue (used by some speakers in uvular trill and fricative production). Because of the connection created by this muscle, a low tongue position may draw down the velum slightly. If the tongue is fixed, it may serve as a depressor to the soft palate.

4. Styloglossus

Attachments: Styloglossus attaches to the anterior and lateral surface of the styloid process and the stylomandibular ligament. The fibers fan out and course inferiorly and anteriorly, dividing into two parts. The lower part blends with the fibers from the hyoglossus muscle. The upper part courses along the lateral edges of the tongue and blends with the fibers from the inferior longitudinal muscle near the tip of the tongue.

Function: Styloglossus elevates and draws back the tongue, acting as an antagonist to genioglossus. These two muscles work together to position the tongue for most vowels. With the posterior part of genioglossus, it helps to bring the tongue up and back for velar articulations. Since the fibers insert on the sides of the tongue, contraction of styloglossus may also elevate the tongue margins to form a groove.

V. MUSCLES OF THE SOFT PALATE

A. ELEVATORS

1. Levator Palatini

Attachments: Levator palatini runs from the apex of the petrous portion of the temporal bone to the posterior surface of the soft palate.

Function: Levator palatini elevates the soft palate and pulls it posteriorly for non-nasal articulations.

2. Muscularis Uvulae

Attachments: Muscularis uvulae runs from the posterior nasal spine of the palatine bones and palatine aponeurosis. It courses medially and posteriorly along the length of the soft palate and inserts in the mucous membrane of the uvula.

Function: On contraction, it shortens and lifts the soft palate and the uvula. It may help to close off the nasal cavity and may play some role in positioning the uvula for a uvular trill.

B. TENSOR

1. Tensor Palatini

Attachments: Tensor palatini runs from the base of the medial pterygoid plate and the lateral wall of the auditory tube. Fibers course inferiorly and anteriorly becoming tendonous as they wind around the hamulus and spread out along the palatine aponeurosis.

Function: Tensor Palatini spreads and tenses the soft palate, helping to close off the nasal cavity. It also pulls on the wall of the auditory tube and opens it up to equalize pressure.

C. DEPRESSORS

1. **Palatoglossus** (see under extrinsic muscles of the tongue)

2. Palatopharyngeus

Attachments: Palatopharyngeus arises in the soft palate with many fibers interdigitating with those from the opposite side. Some fibers arise from the edge of the auditory tube and form the salpingopharyngeus (which I will not discuss here since it has little, if anything, to do with speech). The fibers course inferiorly and laterally, forming the posterior pillar of the fauces, inserting into the stylopharyngeus, the lateral wall of the pharynx and the posterior border and greater cornu of the thyroid cartilage.

Function: When the thyroid cartilage and pharyngeal wall are fixed, contraction of this muscle will lower the soft palate. When the soft palate is fixed, the thyroid cartilage can presumably be raised (mostly for swallowing).

3. Passavant's Muscle

Attachments: This is a part of palatopharyngeus which originates at the posterior border of the hard palate. The fibers course posteriorly along the wall of the nasopharynx and insert into the superior pharyngeal constrictor.

Function: On contraction, this muscle raises a ridge (Passavant's Ridge) against which the levator palatini pulls the soft palate and helps form a better seal. It is particularly developed in keen-scented animals who need to seal off the nasal cavity more thoroughly.

VI. MUSCLES OF THE PHARYNX

A. PHARYNGEAL CONSTRICTORS

1. Superior Pharyngeal Constrictor

Attachments: This muscle has several different origins and a comparable number of names: a) Originating at the lower one-third of the medial pterygoid palate and the hamulus is the pterygopharyngeus; b) Originating at the pterygomandibular raphe is the buccopharyngeus; c) From the posterior part of the mylohyoid line and adjacent alveolar process of the mandible is the mylopharyngeus and d) a few fibers from the side of the tongue are sometimes called the glossopharyngeus. All fibers insert into the midline pharyngeal raphe.

Function: These muscles narrow the upper wall of the pharynx.

2. Medial Pharyngeal Constrictor

Attachments: This muscle can be said to consist of two minor muscles: (a) the ceratopharyngeus which originates on the superior border of the greater horn of the hyoid bone and b) the chondropharyngeus (mentioned before as part of the hyoglossus) is considered by some tom be part of the medial pharyngeal constrictor. The fibers run superiorly and medially to the medial pharyngeal raphe. The superior fibers overlap those of the superior constrictor.

Function: These fibers contract the pharynx during swallowing. Since it attaches on the hyoid bone, it has a minor function as a larynx elevator along with the posterior belly of the digastric and the stylohyoid.

3. Inferior Pharyngeal Constrictor

Attachments: From lamina and superior cornu of the thyroid cartilage and from the sternothyroid muscle arise the fibers called the thyropharyngeus. Other fibers arising from the cricoid cartilage and the inferior cornu of the thyroid cartilage are called the cricopharyngeus. The upper fibers run posteriorly and medially to the midline pharyngeal raphe. The most inferior fibers go obliquely downward to blend with the muscle fibers of the esophagus and form a sphincter.

Function: Cricopharyngeus becomes a pseudo-glottis in laryngectomized patients; it sets the aperture of the esophagus for esophageal speech. From a fixed larynx, the inferior constrictor can constrict the lower part of the pharynx for swallowing.

VII. Extrinsic Muscles of the Larynx

A. Elevators

1. Anterior Belly of the Digastric (see under muscles which lower the mandible)

2. Posterior Belly of the Digastric

Attachments: This portion of the digastric muscle attaches to the mastoid process of the temporal bone. Fibers run inferiorly and anteriorly to meet the anterior belly at an intermediate tendon.

Function: The posterior belly of the digastric draws the hyoid bone superiorly and posteriorly and with it the larynx. It may also help bring the tongue into position for velar articulations.

3. Genioglossus (see under extrinsic muscles of the tongue)

4. Geniohyoid (see under muscles which lower the mandible)

5. Hyoglossus (see under extrinsic muscles of the tongue)

6. Mylohyoid (see under muscles which lower the mandible)

7. Medial Pharyngeal Constrictor (see under muscles of the pharynx)

8. Stylohyoid

Attachments: As the name implies, this muscle originates on the styloid process on the temporal bone. The fibers course inferiorly and anteriorly to insert in the greater cornu of the hyoid bone.

Function: Works with the posterior belly of the digastric to elevate and draw posteriorly the hyoid and with it the larynx. Because the fibers are attached to the greater cornu of the hyoid bone, contraction will cause the hyoid bone and the thyroid cartilage to tilt forward when the sternohyoid acts as a fixator. This may help bring the tongue forward for alveolar, dental and interdental articulations.

B. Depressors

1. Omohyoid

Attachments: This muscle's posterior belly originates on the upper border of the scapula, anterior belly on the intermediate tendon. The posterior belly inserts in the intermediate tendon, where the anterior belly takes over and runs vertically and slightly medially to the lower border of the greater cornu of the hyoid bone.

Function: The omohyoid lowers the hyoid and the larynx, similar to the sternohyoid. It is a very small muscle and probably can't do too much by itself.

2. Sternohyoid

Attachments: Sternohyoid attaches to the posterior surface of the manubrium of the sternum and the medial end of the clavicle. Fibers run vertically to the lower border of the body of the hyoid bone.

Function: The sternohyoid draws the hyoid bone inferiorly and with it the larynx for: lowering F_0 by increasing the superior-inferior thickness of the vocal folds, decreasing supraglottal pressure for maintenance of voicing and for implosives. It also tilts down the anterior part of the hyoid bone for front articulations.

3. Sternothyroid

Attachments: This muscle attaches to the posterior surface of the manubrium of the sternum and the first costal cartilage. The fibers course superiorly and slightly laterally, inserting in the oblique line on the thyroid cartilage.

Function: The function of this muscle is under some dispute. Some investigators call it a larynx lowerer, others a larynx elevator, with some fibers also serving to stabilize, or perhaps raise, the thyroid cartilage.

4. Thyrohyoid

Attachments: This muscle attaches to the oblique line of thyroid cartilage. It runs vertically, deep to the omohyoid and the sternohyoid and inserts in the lower border of the greater cornu of the hyoid bone.

Function: On contraction, the thyrohyoid decreases the distance between the thyroid cartilage and the hyoid bone. When the thyroid cartilage is fixed, it depresses the hyoid bone. When the hyoid bone is fixed, it elevates the thyroid cartilage and raises the pitch. It also tilts the hyoid backwards, which may be appropriate for velar and uvular articulations.

VIII. Intrinsic Laryngeal Muscles

A. Sphincter Muscles for Laryngeal Inlet

1. Aryepiglottis

Attachments: This muscle attaches on the side of epiglottis. Fibers run across apex of each arytenoid across to the muscular process of the opposite arytenoid, with some fibers attaching on the way.

Function: On contraction, the aryepiglottis pulls back the epiglottis (i.e. closes off the laryngeal inlet) by a sphincter action. This is to close off the laryngeal inlet for swallowing and may be used in production of lower pharyngeal articulations.

2. Thyroepiglottis

Attachments: Thyroepiglottis runs from the inner surface of the thyroid cartilage close to the angle superiorly and posteriorly to the aryepiglottic fold.

Function: This muscle depresses the epiglottis to close off the passage for swallowing. It probably has no function in speech.

B. ABDUCTOR

1. Posterior Cricoarytenoid

Attachments: This muscle attaches in the depression on the posterior surface of the cricoid cartilage. The fibers run superiorly and laterally to insert in the posterior surface of the muscular process of each arytenoid.

Function: On contraction, this muscle pulls the arytenoids inferiorly and medially on the shoulders of the cricoid cartilage and rotates them from lateral to posterior. The vocal processes are projected slightly upwards and abducted. EMG studies have shown activity in the production of voiceless stops and fricatives.

C. ADDUCTORS

1. Lateral Cricoarytenoid

Attachments: This muscle attaches on the upper border of the arch of the cricoid cartilage. Fibers run superiorly and posteriorly along the rim of the cricoid cartilage to insert in the muscular process of the arytenoids.

Function: This muscle rotates the arytenoids to approximate the vocal folds. When the vocal folds are already adducted, additional tension in the lateral cricoarytenoid will cause raising of the pitch. Further contraction is said to lead to a slight abduction at the arytenoid and of the folds--the proper position for the production of whisper.

2. Interarytenoids

a. Horizontal fibers

Attachments: Fibers attach to the posterior surface and lateral border of each arytenoid and the lateral edge and muscular process of the opposite arytenoid.

Function: On contraction, this muscle draws the arytenoids together by pulling them up on the shoulders of the cricoid cartilage and elevates them slightly. It may contribute to a raise in F_O.

b. Oblique fibers

Attachments: These fibers run from the lower posterior surface of each arytenoid and course superiorly and obliquely to insert in the apex and the lateral sides of the opposite arytenoid. The two sets of fibers cross each other.

Function: This muscle adducts the vocal folds by bringing the apexes of the arytenoid cartilages together. During forced contraction it can bring the false folds together for "ventricular voice". It also helps the aryepiglottis to close off the vestibule of the larynx.

D. TENSORS

1. Cricothyroid

Attachments: This muscle originates on the lower border and outer surface of the arch of the cricoid cartilage. The lower fibers run posteriorly and superiorly to insert into the anterior margin of the inferior cornu of the thyroid cartilage. The upper fibers course vertically upwards to insert into the inner part of the inferior margin of the thyroid cartilage.

Function: The basic function of this muscle appears to be to elongate and thus increase the tension in the vocal folds in order to raise the pitch. If the thyroid cartilage is fixed, it raises the anterior part of the cricoid towards the anterior part of the thyroid, while tilting the posterior part of the cricoid backwards. If the cricoid cartilage is fixed, the cricothyroid muscle tilts the anterior part of the thyroid cartilage downwards. In both cases, the distance from the angle of the thyroid cartilage and the arytenoids is increased, thereby stretching the vocal fold.

2. Vocalis

Attachments: Fibers originate in the posterior and inferior half of the angle of the thyroid cartilage. Coursing posteriorly, the fibers insert into the vocal processes of the arytenoids near the vocal ligament.

Function: The vocalis is actually part of the thyroarytenoid muscle. There is no physical sign of a division, but various investigators have suggested that it may be capable of independent contraction. It forms the muscular part of the vocal folds themselves. The vocalis is the internal vocal fold tensor, to stiffen folds and thus raise the pitch, providing fine adjustments in vocal fold stiffness. It also may shorten the vocal folds thus lessening the tension and decreasing F_0, acting antagonistically to muscles which lengthen the folds, such as the cricothyroid.

E. RELAXER

1. Thyroarytenoid

Attachments: Thyroarytenoid attaches on the inner surface of the thyroid cartilage at the angle. The fibers course posteriorly, more or less parallel to the vocal ligament and insert in the muscular process of the arytenoids. some fibers go around the lateral border of the arytenoids and interdigitate with the oblique fibers of the interarytenoids, others with fibers of the lateral cricoarytenoid.

Function: On contraction, the thyroarytenoid pulls the arytenoids up on the shoulders of the cricoid cartilage, thereby shortening and thus relaxing the vocal folds. It also has been cited as a tensor muscle which tenses the folds internally (vocalis) while the thyroarytenoid shortens them.

Appendix C: Annotated Bibliography

ABD-EL-MALEK, S. (1939). Observations on the morphology of the human tongue. Journal of Anatomy, 73: 201-210.

The best description so far of the muscles of the tongue, based on dissections and experimental work. Most writers quote him. Contains a very good description of the septa of the tongue, usually not found in most anatomy books in such detail. The median, paramedian and lateral septa are described. Diagrams and plates support a very detailed description of the muscles of the tongue. Unfortunately, no attempt is made to suggest the way in which the muscles participate in the different movements of the tongue.

CLEMENTE, C.D. (1975). Anatomy: a Regional Atlas of the Human Body. Philadelphia: Lea and Febiger.

Beautiful, color illustrations created from clear, bold and complete drawings originally by the German anatomist Sobatta. Sequence goes from the pectoral region through the thorax, vertebral column and spinal cord, and, finally, the neck and head. Uses English rather than Latin labels, consistent with Gray's Anatomy. Illustrations with complex textural differences are often supplemented by schematic diagrams.

DABELOW, R. (1951). Vorstudien zu einer Betrachtung der Zunge als funktionelles System: II. Die Muskulatur und ihre bindegewebigen Insertionen (Preliminary studies of the tongue as a functional system: II. The musculature and its interdigitated insertion). Gegenbaurs Morphologisches Jahrbüch, 91: 33-76. (In German).

An anatomical investigation of human (as well as other mammalian) tongues, with many excellent photographs and diagrams. Disagrees with Abd-El-Malek (1939): "The [median] septum is no fibrous dividing wall but a complicated linkage of the transverse muscles. The longitudinal musculature consists of bow-shaped pieces which are shortest near the surface and get longer as they get farther towards the depth. Those even deeper are completed by styloglossus fibers." (Quote taken from English abstract.)

DIAMOND, M.C., SCHEIBEL, A.B. and ELSON, L.M. (1985). The Human Brain Coloring Book. New York: Barnes and Noble.

Good source for illustrations, and coloring in if you desire! Drawing by hand is another good method of appreciating how structures connect.

DICKSON, D.R. and MAUE, W.M. (1970). Human Vocal Anatomy. Springfield, Illinois.

Aimed at the beginning speech science student. Focuses on musculature of respiration, phonation, articulation and mastication. Concise, and useful for illustrations of the palatopharyngeal region. Otherwise superceded by the more expansive and detailed Dickson and Maue-Dickson (1982).

DICKSON, D.R. and MAUE-DICKSON, W. (1982). Anatomical and Physiological Bases of Speech. Boston: Little, Brown & Co.

Designed for both beginning and advanced students. Contains useful background information at the outset, then the same coverage as Dickson and Maue (above), but in greater textual detail, and with an additional chapter on the nervous system. Much attention given to basic principles of structure and function of neuromuscular system in order to better understand the physiology. Many invaluable diagrams and photographs.

GRANT, J.C.B. (1962). Grant's Atlas of Anatomy. Baltimore: Williams and Wilkins.

A good general reference to have available in the course. Generally, the figures in Pernkopf are clearer.

HARDCASTLE,W.J. (1976). Physiology of Speech Production: an Introduction for Speech Scientists. London: Academic Press (London) Ltd.

Includes several excellent schematic diagrams of complicated muscle interactions and concrete discussion of physiological correlates of traditional speech sound categories (i.e. stop, fricative, tap, trill, etc.). Several chapters are organized around muscles involved in particular actions, their attachments, innervation, etc.

HILL, K. (1964). The musculature of the tongue. UCLA Working Papers in Phonetics, 1: 22-39.

Simple overall description of the suprahyoid muscles, the intrinsic muscles of the tongue, the extrinsic muscles of the tongue, and the connective tissue structure of the tongue. Explanations in the text are very thorough , intelligible and helpful for comprehending the composition of the tongue and surrounding framework. Fourteen figures and and extensive annotated bibliography.

KAHANE, J.C. and FOLKINS, J.W. (1984). Atlas of Speech and Hearing Anatomy. Columbus: Charles E. Merrill.

A unique and comprehensive book of photographs from anatomical specimens. Some are fiberoptic while others come from dissections and photomicrographs. Actual preparations are largely favoured over drawings, but occasionally drawings and illustrations are taken from the literature to clarify certain anatomical concepts. Fascinating, and essential for this course.

KAPIT, W. and ELSON, L.M. (1977) . The Anatomy Coloring Book. New York: Harper and Row.

Similar resource to Diamond et al.'s Human Brain Coloring book, described above. Many of the plates for the speech organs are based on Clemente (q.v.). Again, doing is learning!

LANZ, T. von and WACHSMUTH, W. (1955). Praktische Anatomie: I/2 Hals. Berlin: Springer Verlag.

Many figures and descriptions of suprahyoid and infrahyoid muscles, including the muscles of the tongue on pp. 63-122. Very clear drawings.

MATT, M. and ZIEMIAN, J. (1982). Human Anatomy Coloring Book. New York: Dover.

Designed for use by high school teachers, but nevertheless another useful source for clear and easy-to-adapt illustrations. Entertaining and instructive guide to the human body—bones, muscles, blood, nerves, and how they work.

MIYAWAKI, K. (1974). A study of the musculature of the human tongue: observations on transparent preparations of serial sections. Annual Bulletin, Research Institute of Logopedics and Phoniatrics, University of Tokyo, 8: 23-50.

Thorough description of muscles of the tongue. Then three tongues dissected in three planes: sagittal, coronal and transverse. Sections made transparent, revealing the direction of the muscle fibres very clearly. Complete series of drawings then made from the sections. The paper also contains a mini-bibliography relating to the tongue.

PERNKOPF, E. (1963). Atlas of Topographical and Applied Human Anatomy. Vol. 1, Head and Neck. Philadelphia: Saunders.

Pages 136-141 have very useful pictures of the tongue, its muscles, and the area around it. No text. Seems to be the best atlas for our purpose.

SPALTEHOLZ, W. (1933). Hand Atlas of Human Anatomy. Philadelphia: J.B. Lippincott.

Vol. 3, pages 508-509 give pictures of the tongue muscles with basic, clear explanations. Lip muscles are generally described, but not much more than in most anatomy books.

STRONG, L.H. (1956). Muscle fibers of the tongue functional in constant [sic] production. Anatomical Record, 126: 61-79.

An important article, illustrated with excellent photographs of sections of the tongue. Carries on the work of Strong and Gold (1950), investigating how the intrinsic tongue musculature would deform the tongue to conform to the outlines of palatograms. Rather naive about palatograms and tongue positions, confusing hypothesis concerning the action of the transverse and vertical muscles which are supposed to act in a special way in consonants. Interesting critical review of the anatomical literature, showing some of the nineteenth-century sources of Gray, Cunningham and Spalteholtz. Mentions existence of Abd-El-Malek (1939), but pays no attention to his work. The word "constant" in the title (and one line of the article) is a typographer's error, corrected in an Erratum in a later issue; Strong intended "consonant".

ZEMLIN, W.R. (1968). Speech and Hearing Science. Second edition. Englewood Cliffs: N.J.: Prentice Hall.

Excellent descriptions of speech organs' physiology and pathologies. Written for the speech science audience.